BE/BAT 485/585

Remote Sensing Data and Methods

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Today we Will

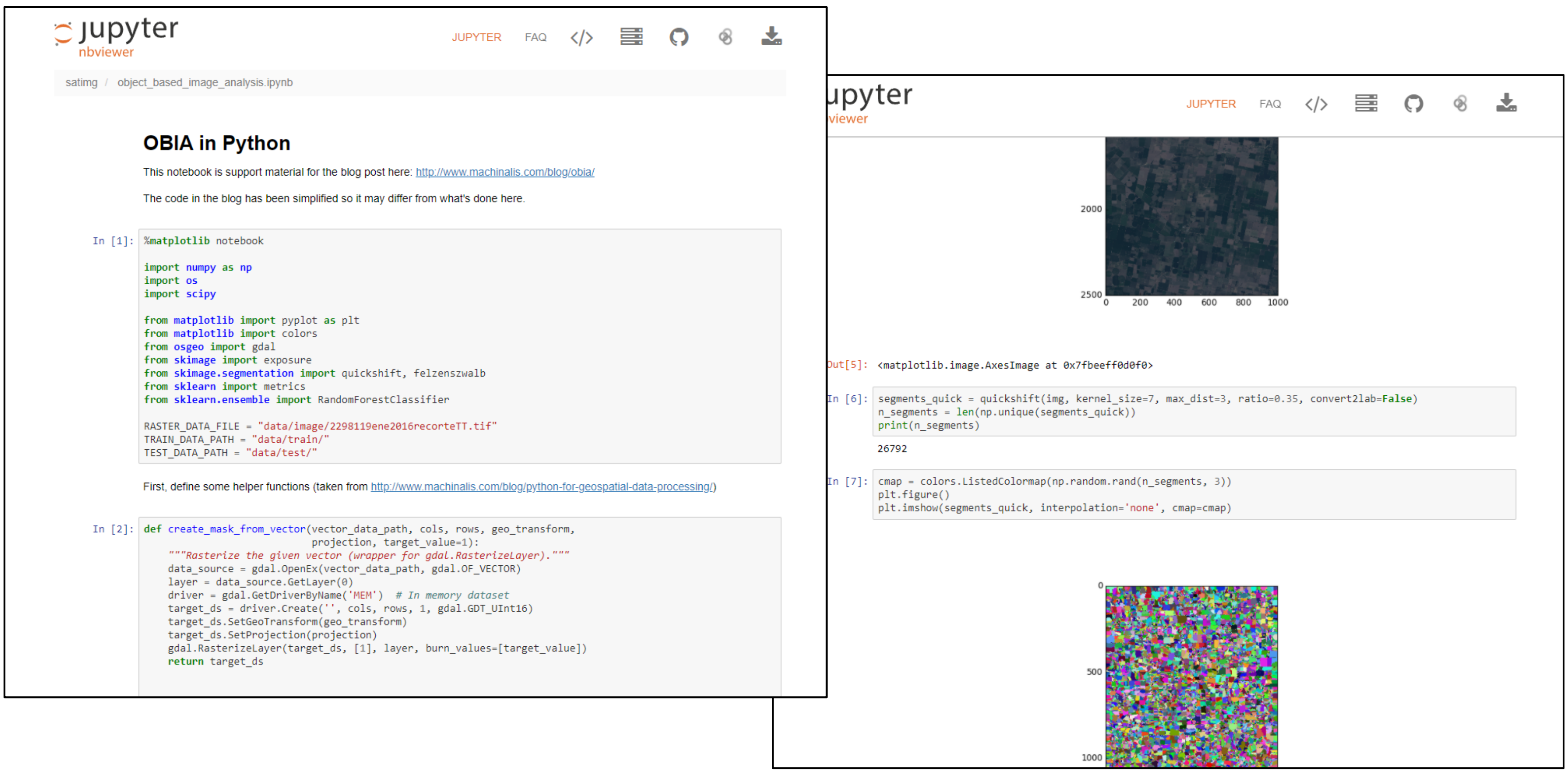
- More class orientation, especially labs.
- Introduce basic RS concepts
- HW#2

Labs and Lab Reports

- You will notice that on most occasions there are no specific instructions for labs.
- They were designed for you to follow, explore, understand, then modify and augment them in a way to address the lab. objectives
- Your job is to be creative:
  - Modify the code
  - Think of the audience and reproducibility
  - Address the objectives
    - Like how you would write a manuscript (Abstract/Intro, Methods, Data, Results, and if any conclusions or observations worth sharing)
    - Make it a Live report: Interactive + Markdown + Equations + Images + Figures , etc.

Here are some Examples

- http://pythonic.zoomquiet.top/data/20171227234039/index.html
- About Images:
  - https://nbviewer.org/github/machinalis/satimg/blob/master/object_based_image_analysis.ipynb



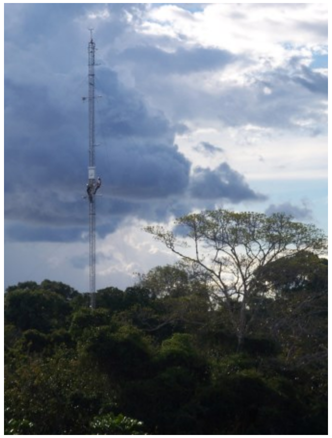
Up to Now

- We discussed a general context focused on how Earth and the Environment are changing
  - Temperature and Precipitation are two measures that encapsulate this change
  - Modelling helps us understand long term impacts
  - These changes require monitoring and planning
- Observation/Monitoring can be in situ (limited, not thorough, and maybe misleading)
- Models can help us predict
  - Prediction helps us improve lives and use resources properly and sustainably
- Remote sensing is a technology/tool that can address the spatial aspect, data needs, and practical monitoring of these challenges

In situ Observations/Measurements

- Recall the goal is to be able to **model** and **predict**
  - Think of an example?
- In that regards :
  - Scientists and based on observations and measurements formulate ***hypotheses*** and then
  - Attempt to accept or reject them in a **systematic** and **unbiased** fashion
    - **Systematic**: logical, unfailing, repetitive and orderly
    - **Unbiased**: balanced, impartial, applies everywhere with no exceptions
  - The data necessary to ***accept*** or ***reject*** a hypothesis may be collected directly in the field, often referred to as *in situ* or *in-place (field)* data collection.
  - But this can be a time-consuming, expensive, and inaccurate process
    - Why inaccurate?

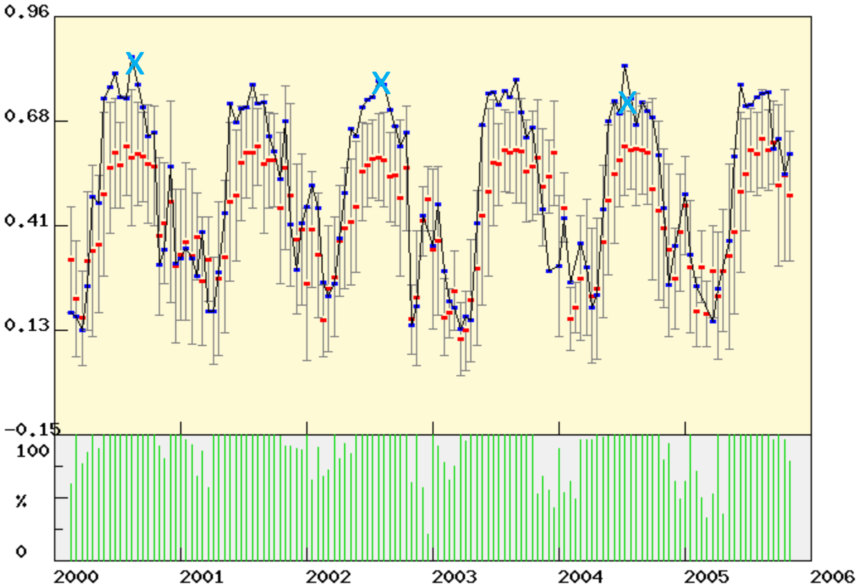
How to Measure and Monitor?



Few meters to
few hectares
Time series

Very Time consuming

Few
hectares/transects
One time



In situ Observations/Measurements challenges

- Collecting data in the field can be related to **biased procedures** referred to as '***<u>method-produced error</u>***'.
  - An interesting example is we are "*very Earth centric/biased*"
- Such error can be introduced by:
  - Sampling design does not capture the spatial variability of the phenomena under investigation
    - **Examples**: Some phenomena or geographic areas are oversampled while others are under-sampled
    - Can you think of an example?
  - Improper operation of *in situ* measurement instruments; or
    - Can you think of an example?
  - Uncalibrated *in situ* measurement instruments
    - Can you think of an example?

Ground Reference Information vs. Ground Truth

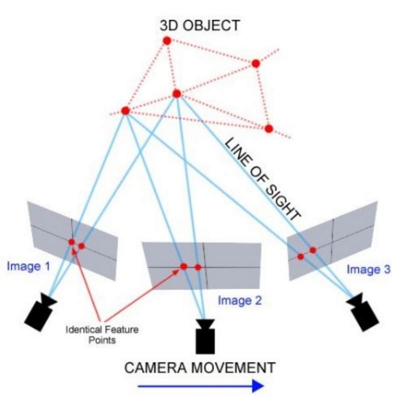
- Could '***in situ* data**' be '***ground truth data***'? Yes or No
  - Why?
- Generally it should be referred to as '***in situ ground reference data***', to acknowledge the potential for **error**
- For all practical purposes "in situ" data is the closest to truth (true data that is free of most issues) and could be used to validate and characterize other data
  - Recall this is in the context of data collected by cameras/sensors?
- As we progress in this course we will learn/realize there are lots of issues (**+/-**) as the energy interacts with everything in its path accounting for both the characteristics of the objects being observed but also 'tainted' with the characteristics of the medium and the environment where the objects live/reside

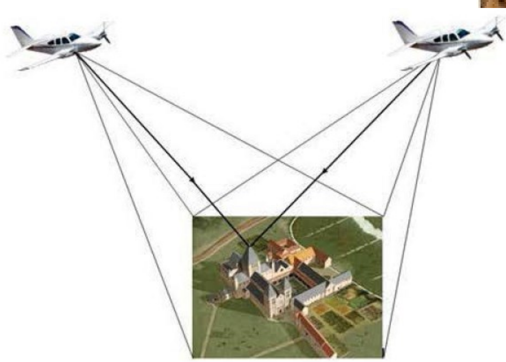
So what is Remote Sensing?

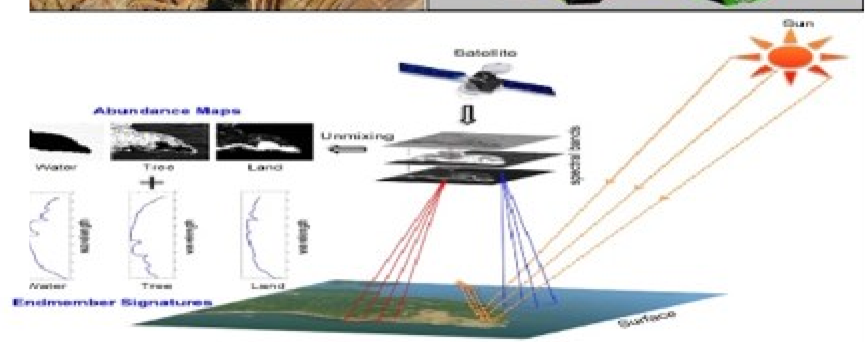
- There are many definitions, and they are probably all correct, however the "American Society for Photogrammetry and Remote Sensing [**ASPRS**] adopted the following formal definition to describe *photogrammetry* and *remote sensing* as (Colwell, 1997):
  - *In Photogrammetry:* Remote Sensing is "the art, science, and technology of obtaining **reliable** information about **physical objects and the environment**, through the process of **recording**, **measuring** and **interpreting imagery** and **digital** representations of **energy patterns** derived from **noncontact** sensor systems".

Photogrammetry

- It is a 3-dimensional coordinate measuring technique that uses photographs as the fundamental medium (basis) for ***metrology*** (or measurement).
- The fundamental principle used by Photogrammetry is **triangulation** or more specifically called **Aerial Triangulation**.
- By taking photographs from at least two different locations, so-called "**lines of sight**" can be developed from each camera to points on the object.
- These lines of sight (sometimes called rays owing to their optical nature) are **mathematically intersected** to produce the 3-dimensional coordinates of the points of interest (used in Structure from Motion to reconstruct 3D space).
- The expression photogrammetry was first used by the Prussian architect Albrecht Meydenbauer in 1867 who fashioned some of the earliest topographic maps and elevation drawings. Photogrammetry services in topographic mapping is well established but in recent years the technique has been widely applied in the fields of architecture, industry, engineering, forensic, underwater, medicine, geology and many others for the production of precise 3D data.







Branches of photogrammetry

- There are 2 main and broad based branches in photogrammetry:
  - **Metric Photogrammetry** : Deals with the precise measurements and computations on photographs regarding the size, shape, and position of photographic features and/or obtaining other information such as relative locations (coordinates) of features, areas, volumes, These photographs are taken using a metric camera and is mostly used in the engineering fields e.g. surveying
  - **Interpretive Photogrammetry**: Deals with recognition and identification of the **photographic features** on a photograph such as shape, size, shadow, pattern, etc. to add value and intelligence to information seen on the photograph (annotation).

Remote Sensing

- It is a closely aligned technology to photogrammetry in that:
  - It also collects information from imagery.
  - The term is derived from the fact that information about objects and features is collected without coming into contact with them.
- Remote sensing differs from photogrammetry in many ways:
  - The type of information collected, which tends to be based on **differences in color** (spectra)
    - Ex: Land use and land cover are some of the primary output of remote sensing processing
  - Remote sensing was originally conceptualized to **exploit** the **large number of color bands** in satellite imagery to create 2D data primarily for spatial analysis (ex: using GIS).
  - These days, remote sensing tools/software are used with all types of imagery to assist in 2D data collection and derivation, such as biophysical or physical info (ex: slope).
  - Software tools today tend to hold a much wider range of image technologies such as image mosaicking, 3D visualization, GIS, radar, Lidar

In situ Measurement in Support of Remote Sensing

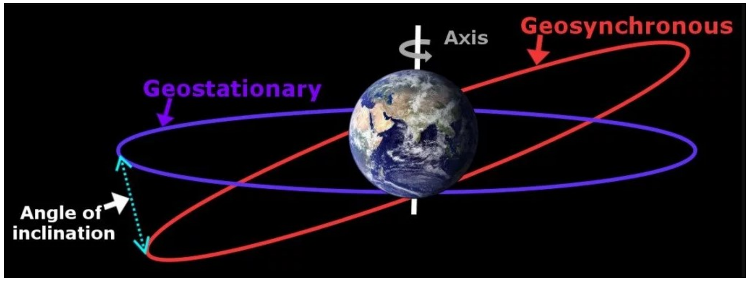
- To be of greatest value, the original remotely sensed data must usually be calibrated in two distinct ways:
  - It should be **geometrically** (x,y,z) and **radiometrically** (e.g., to percent reflectance) calibrated so that remotely sensed data obtained on different dates (or places) can be compared with one another.
  - The remotely sensed data must usually be calibrated/validated (compared) with what is on the ground in terms of biophysical (e.g., leaf-area-index, biomass, temperature, spectral reflectance) or cultural characteristics (e.g., land use/cover, population density, land cover type).
- **Fieldwork** is then necessary to achieve both of these objectives.

- Thus, a person who understands how to collect meaningful field data about the phenomena under investigation is much more likely to use the remote sensing data/science wisely and understand its limitations.

TYPES OF PLATFORMS

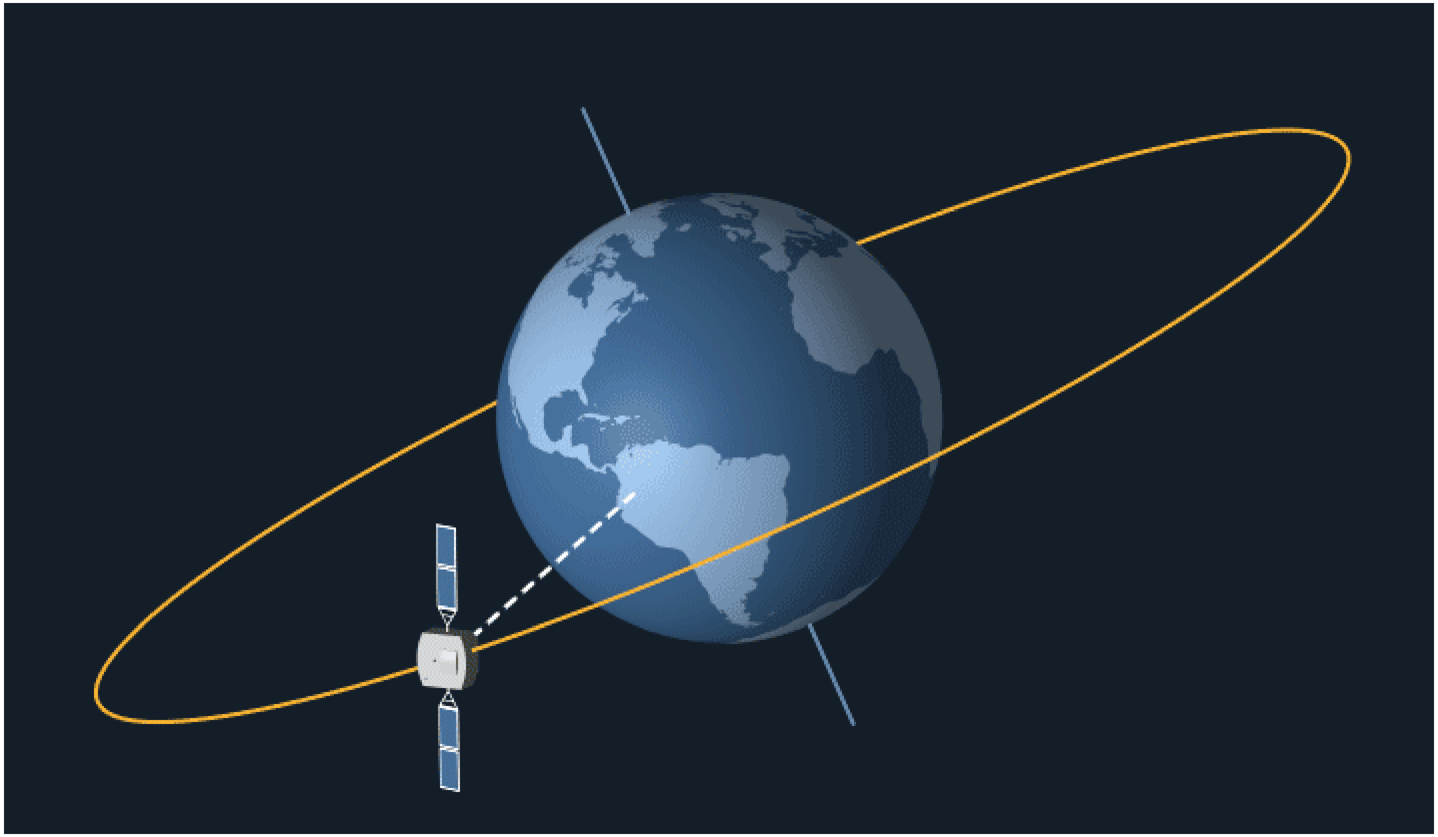
Geosynchronous/Geostationary Platforms

- A **geosynchronous satellite** is a satellite in geosynchronous orbit, with an orbital period the same as the Earth's rotation period.
- Such a satellite returns to the same position in the sky after each 'day', and over the course of a day traces out a path in the sky that is typically some form of **analemma**.
- A special case of geosynchronous satellite is the **geostationary satellite**, which has a geostationary orbit – a circular geosynchronous orbit directly above the Earth's equator.
- Another type of geosynchronous orbit used by satellites is the Tundra elliptical orbit.
- Geosynchronous satellites have the advantage of remaining permanently in the same area of the sky, as viewed from a particular location on Earth, and so permanently within view of a given ground station.
- Geostationary satellites have the special property of remaining permanently fixed in exactly same position in the sky, as viewed from any location on Earth, meaning that ground-based antennas do not need to track them but can remain fixed in one direction.
- Such satellites are often used for communication purposes and weather; a **geosynchronous network** is a communication network based on communication with or through geosynchronous satellites.
- **Geostationary satellite examples**
  - American GOES (Geostationary Operational Environmental Satellite) series, the Indian INSAT satellites, Japanese Himawari, European Meteostat and Chinese Fengyun.



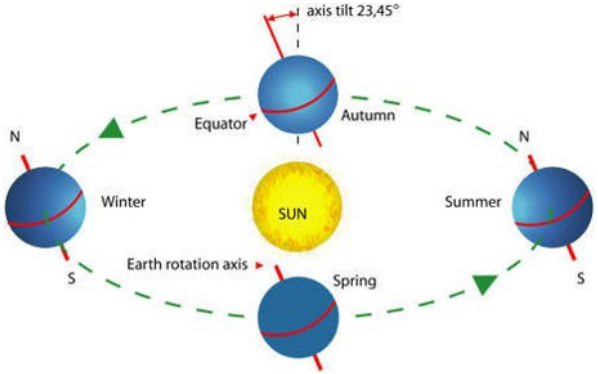
analemma

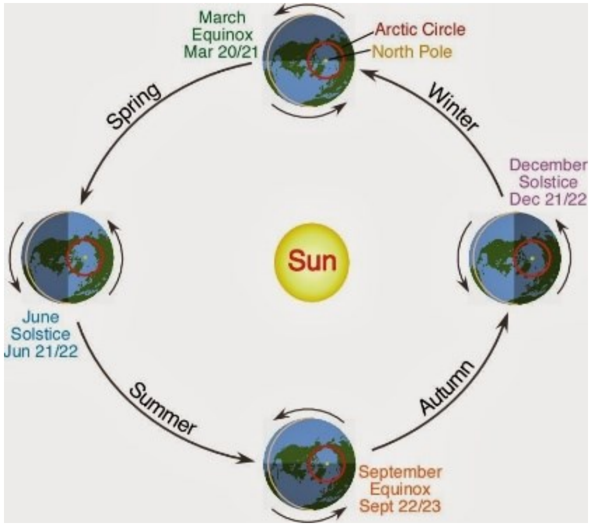
Geostationary Satellite



So what is a Sidereal day?

- So what is a year exactly?
  - It turns out there are few slightly different definitions
  - The time it takes a physical body to orbit another?
  - **Tropical Year (365.242 d)**: The time it takes the Earth Tilt Angle to come back to the same position relative to the sun
  - **Sidereal Year (365.256 d)**: The time it takes the Earth to come back so we can see the same stars rising behind the sun
  - **Anomalistic year (365.26)**: The time it takes the Earth to come back to the closest approach to the sun
- And what is a day then?
  - The time it takes the Earth to rotate 360 degrees around itself? Is it?
  - An issue arises because while the Earth is rotating around itself it also rotates around the Sun.
  - So even after 360 degrees the Sun is not exactly at the same position with respect to Earth (noon?). The Earth needs to rotate a little bit more
  - This is called a **Sidereal Day (**23hr 56 min 4 s**)**
  - The noon to noon (same sun position) is called a solar day
  - So the Earth orbits the sun in about 366.26 Sidereal days or 365.26 Solar Days
  - Both Sidereal and Solar day change ever slightly throughout the year due to the Earth orbit shape (speed)





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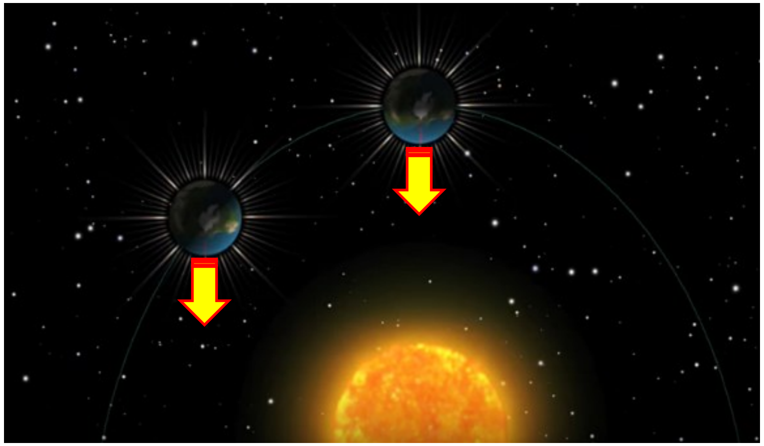
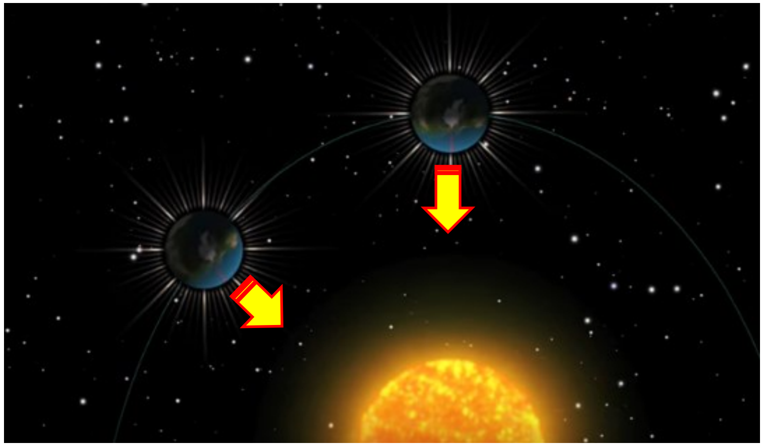
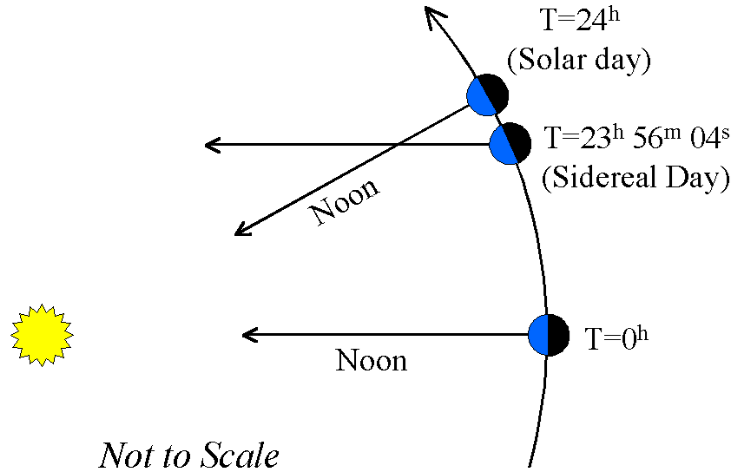


360 degrees



> 360 degrees

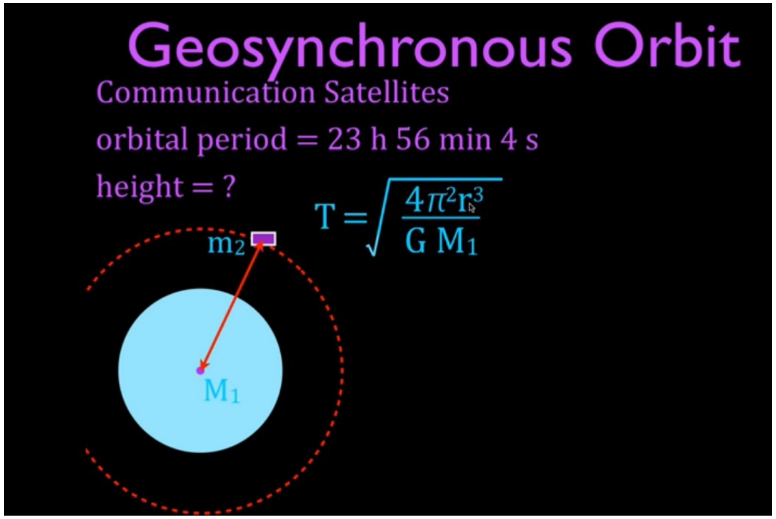


Geosynchronous/Geostationary Radius

- How to compute the Period or Radius (height AGL)
- Because these platforms are geosynchronous their period is a **<u>full sidereal day</u>**

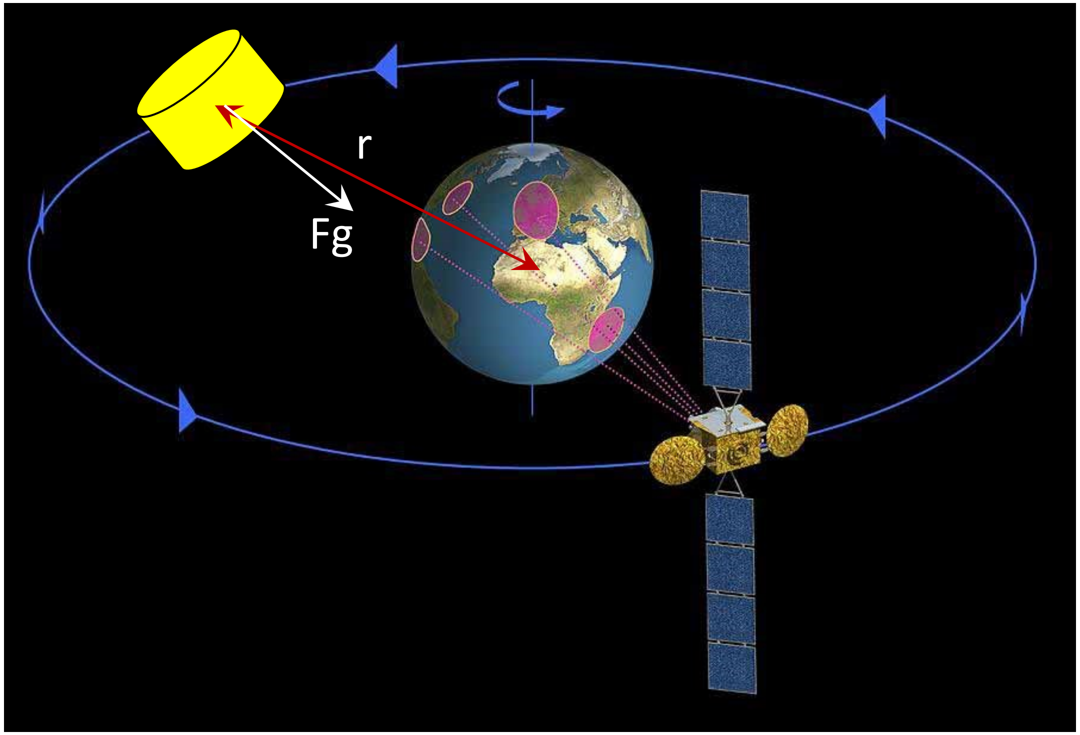
  = 23hr 56 min 4 s = 86,164 s

- Their period is computed following this equation $T = \sqrt{\frac{4\pi^2 r^3}{G\ M_1}}$
- Where:
  - G = Gravitational constant, universal gravitational constant, or Newton's constant = 6.674×10^{-11} $m^3\cdot kg^{-1}\cdot s^{-2}$
    - [Cavendish experiment, in 1798] G of 6.754×10^{-11} $m^3\cdot kg^{-1}\cdot s^{-2}$
    - [Fixler et al, January 2007, Science,] G = $6.693(34)\times10^{-11}$ $m^3\cdot kg^{-1}\cdot s^{-2}$
    - [Improved cold atom measurement by Rosi et al., 2014] G = $6.67191(99)\times10^{-11}$ $m^3\ kg^{-1}\ s^{-2}$
  - M1= Earth Mass = $5.972 \cdot 10^{24}$ kg
  - r = Orbit radius ?
- $r = 3\sqrt{\frac{T^2 G\ M_1}{4\pi^2}}$
- By substitution r = 42,164km
- AGL(r)= r – Earth Radius (6371km) = 35,793km



How did we derive this?

- Lets derive the Radius (Orbit height) of the satellite so it stays synchronized (Geosynchronous) with the Earth Rotation?
- The only force acting on the Satellite is gravitational pull or force [Fg]?



- Lets formulate the equation that govern this body?

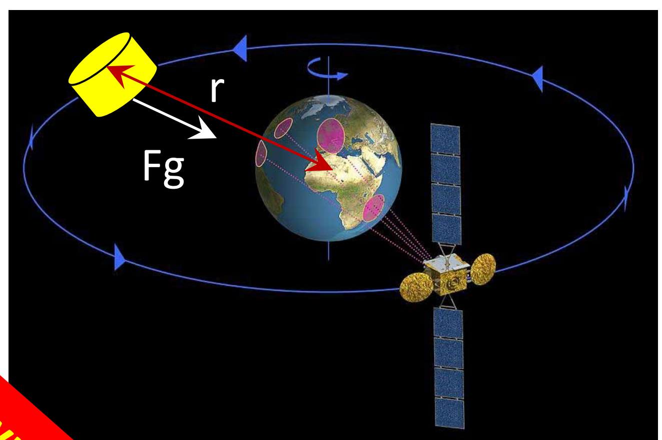
Read this on your own

How did we derive this?

- And because we are far away from the Earth surface we need to use Newton’s Universal Law of Gravity and recognize that the satellite is also under a centripetal force (pull) = m.a (a being acceleration)

$$\mathbf{Fg} = \frac{G.M.m}{r^2} = m.a$$

  - G : Universal constant
  - M = Mass of Earth
  - M = Mass of satellite
  - R = Distance between Earth (center) and Satellite
  - a = Centripetal Acceleration (= v^2/r)



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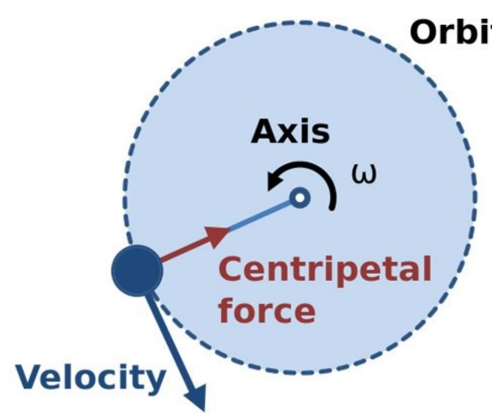


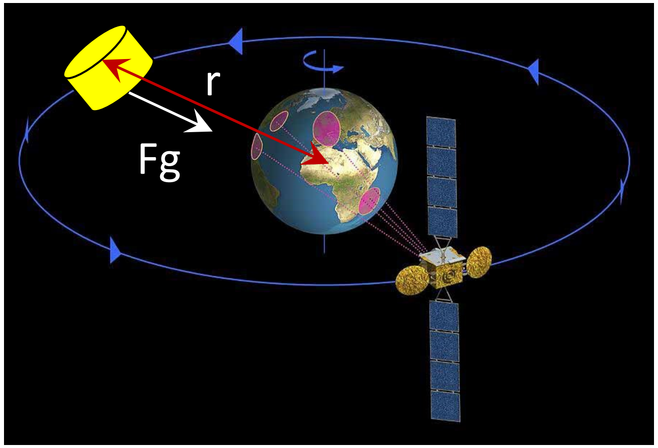
How did we derive this?

- The Centripetal Acceleration **a = v²/r**
- So: $Fg = \frac{G.M.m}{r^2} = m.\frac{v^2}{r}$
  - We need to find r? and the only unknown is v (speed) in the Eq?
  - And v = Distance/Time
  - Distance is circumference = 2 π r
  - T = Period (or in the case of the geosynchronous satellites it is a day = ~24 hrs)
  - $V = 2 \pi r/T$ and $V2 = 4\pi^2 r^2 / T^2$
- And if we substitute, rearrange and cancel, we get

$$\frac{G.M.m}{r^2} = m\frac{4\pi^2 r^2}{r.T^2} \quad \text{or} \quad \frac{G.M}{4\pi^2}T^2 = r^3$$

- and $T = \sqrt{\frac{4\pi^2 r^3}{G\,M_1}}$ or $r = 3\sqrt{\frac{T^2 G\,M_1}{4\pi^2}}$

Read this on your own



How did we derive this?

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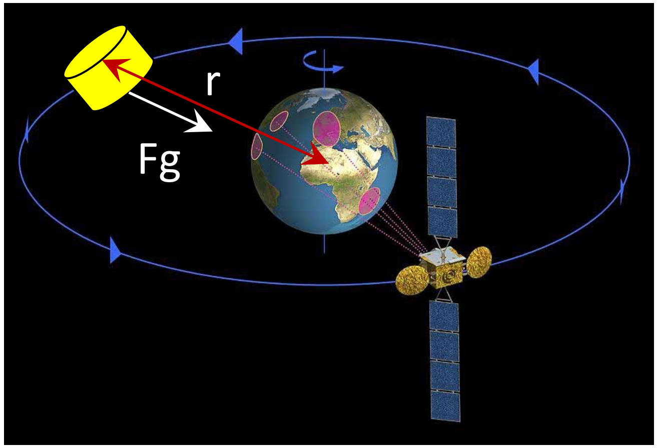


Read this on your own

Polar Orbiting Platforms

- A **polar orbit** platform is one in which the **satellite** passes above or nearly above both poles (N and S) of the body being **orbited** (usually a planet such as the Earth, and possibly another body such as the Moon or Sun) on each revolution.
- It therefore has an inclination of (or very close to) 90 degrees to the poles
- A satellite in a polar orbit will pass over the equator at a different longitude on each of its orbits.
- Polar orbits are **<u>often used for earth-mapping, earth observation</u>**, capturing the earth as time passes from one point, reconnaissance satellites, as well as for some weather satellites. The Iridium satellite constellation also uses a polar orbit to provide telecommunications services. The disadvantage to this orbit is that no one spot on the Earth's surface can be sensed continuously from a satellite in a polar orbit.
- **Sun orbits**
  - Recall the source of energy/illumination
  - Near-polar orbiting satellites commonly choose a Sun-synchronous orbit, meaning that each successive orbital pass occurs at the same **<u>local time of day</u>**.
  - This can be particularly important for applications such as remote sensing atmospheric temperature, where the most important thing to see may well be *changes* over time which are not aliased onto changes in local time.
  - To keep the same local time on a given pass, the time period of the orbit must be kept as short as possible, this is achieved by keeping the orbit lower to the Earth. However, very low orbits of a few hundred kilometers **<u>rapidly deca</u>**y due to drag from the atmosphere.
  - Commonly used altitudes are between 700 km and 800 km, producing an orbital period of about 100 minutes.
  - The half-orbit on the Sun side then takes only 50 minutes, during which local time of day does not vary greatly.
- To retain the Sun-synchronous orbit as the Earth revolves around the Sun during the year, the orbit of the satellite must precess at the same rate, which is not possible if the satellite were to pass directly over the pole. Because of the Earth's equatorial bulge, an orbit inclined at a slight angle is subject to a torque which causes precession; an angle of about 8 degrees from the pole produces the desired precession in a 100-minute orbit.
  - **Precession** is a change in the orientation of the rotational axis of a rotating body.

[Polar Orbiting Animation]

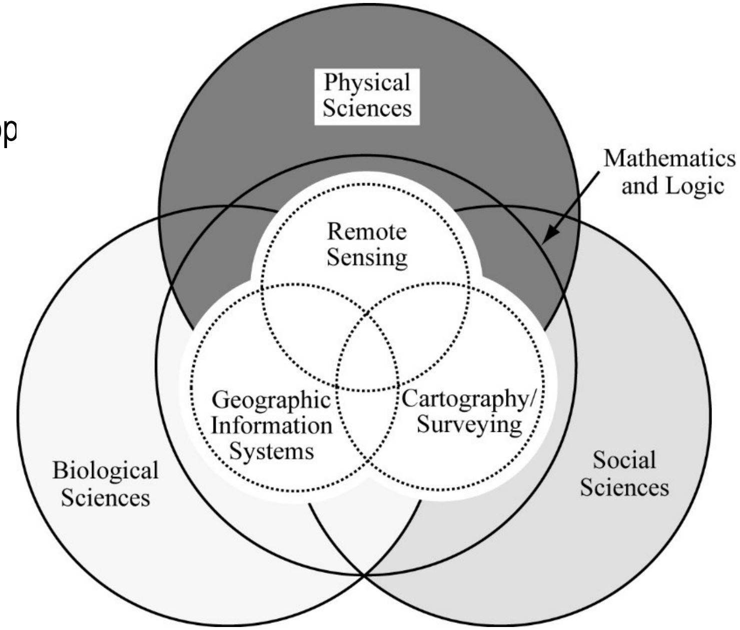
Polar Orbiting Platform

Polar Orbiting Platform

- Polar orbiting (sun-synchronous) are designed to standardize observations globally.
  - How?

So is Remote Sensing a Science?

- A *science* is defined as the broad field of human knowledge concerned with facts (defensible truth) held together by *principles* (rules).
- Scientists discover and test facts and principles using scientific methods
  - An orderly system of solving problems.
  - Scientists generally think that any subject that we can study by using the scientific methods and other special rules of thinking may be called a **science**.
  - The sciences include
  - 1) M*athematics* and *logic*,
  - 2) The *physical sciences*, such as physics and chemistry,
  - 3) The *biological sciences*, such as botany and zoology, and
  - 4) The *social sciences*, such as geography, sociology, and anthrop



So is Remote Sensing a Science?

- Remote sensing is a mix of tools and techniques similar to mathematics.
- Using sensors to measure the amount of electromagnetic radiation (EMR) exiting an object or geographic area from a distance and then
- Extracting valuable information from that data using mathematically and statistically based algorithms is a *scientific* activity.
- It functions in harmony with other *spatial* data-collection techniques or tools of the *mapping sciences*, including cartography and geographic information systems (GIS) (Clarke, 2001).

So is Remote Sensing an Art?

- Visual image interpretation brings to bear not only scientific knowledge and exact methodology and tools but all of the '***experience***' that a person has obtained in a lifetime.
- The synergism of combining scientific knowledge with real-world analyst experience allows the interpreter to develop ***heuristic*** rules of thumb to extract information from the imagery.
- Some image analysts are superior to other image analysts because they
  - 1) Understand the scientific principles better,
  - 2) Are more widely traveled and have seen many landscape objects and geographic areas, and/or
  - 3) Have the ability to synthesize scientific principles and real-world knowledge to reach logical and correct conclusions.
- Thus, remote sensing image interpretation is a science but also an ***<u>art</u>***

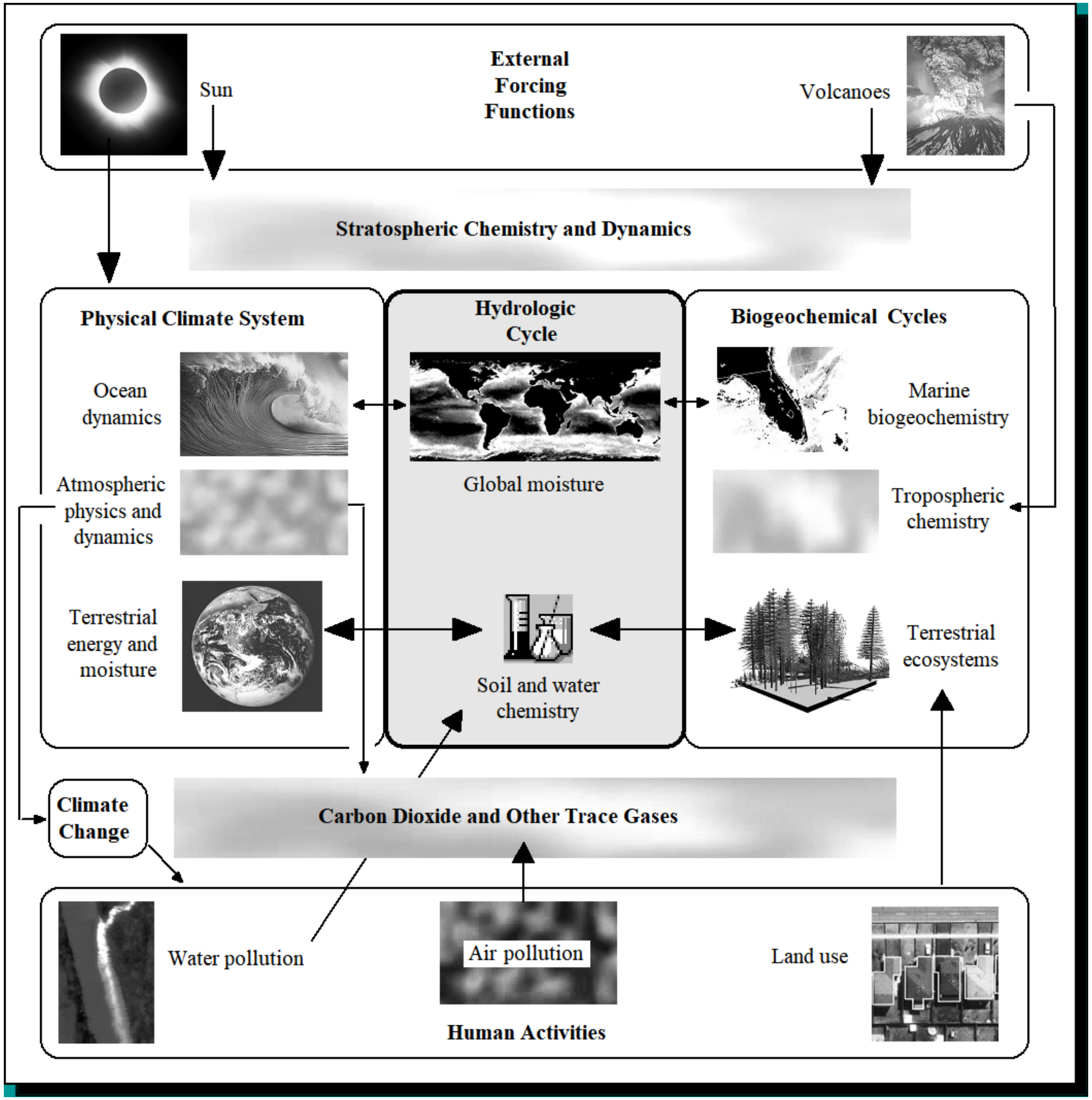
Information about an Object or Area

- Sensors can be used to obtain specific information about an object
  - e.g., the Size of a city block or the distance between two objects in an image
- Or the geographic extent of a phenomenon
  - e.g., the boundary/size of an object (like a lake)
- The EMR reflected, emitted, or back-scattered from an object or geographic area is used as a ***surrogate*** (proxy) for the actual property under investigation
  - In other words we do not measure directly the property/metric
- The electromagnetic energy measurements must be calibrated/standardized and turned into information using visual and/or digital image processing techniques.

Advantages of Remote Sensing

- Remote sensing is ***unobtrusive*** if the sensor *passively* records the EMR reflected or emitted by the object of interest.
- Passive remote sensing does not disturb the object or area of interest.
- Remote sensing devices may be programmed to collect data systematically, such as within a N×N m window/frame of vertical aerial photography.
- This systematic data collection can remove the sampling bias introduced in some *in situ* investigations.
- Under controlled conditions, remote sensing can provide fundamental biophysical information, including *x,y* location, *z* elevation or depth, biomass, temperature, and moisture content.
- Remote sensing–derived information is now critical to the successful modeling of numerous natural (e.g., water-supply estimation; eutrophication studies; nonpoint source pollution) and cultural (e.g., land-use conversion at the urban fringe; water-demand estimation; population estimation) processes (Walsh et al., 1999; Stow et al., 2003).

Remote Sensing Earth System Science

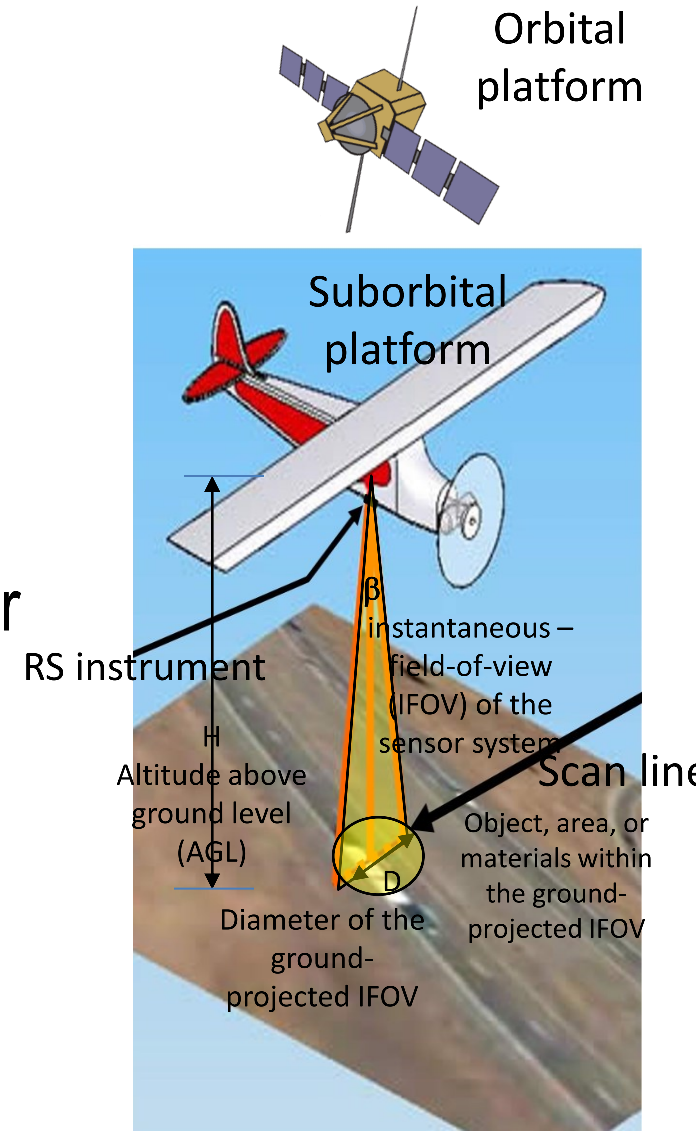


Limitations of Remote Sensing

- The greatest limitation & issues is that it is quite often ***oversold***.
- *Remote sensing is not a* ***panacea*** that provides all the information needed to conduct physical, biological, or social science research.
- It provides some spatial, spectral, and temporal *information* of value in a manner that we believe and strive to make it efficient and economical.
- *Human beings* select the appropriate remote sensing system to collect the data, specify the various resolutions of the remote sensor data, calibrate the sensor, select the platform that will carry the sensor, determine when the data will be collected, and specify how the data are processed.
- Human **method-produced error** may be introduced as the remote sensing instrument and mission parameters are specified.
- Powerful *active* remote sensor systems that emit their own electromagnetic radiation (e.g., LIDAR, RADAR, SONAR) can be intrusive and affect the phenomenon being investigated. Additional research is required to determine how intrusive these active sensors can be.
- Remote sensing instruments may become ***uncalibrated***, resulting in **uncalibrated** remote sensor data.
  - A famous example is the drift over time of platforms (AVHRR sensor for example)
- Remote sensor data may be *expensive to collect and analyze*.

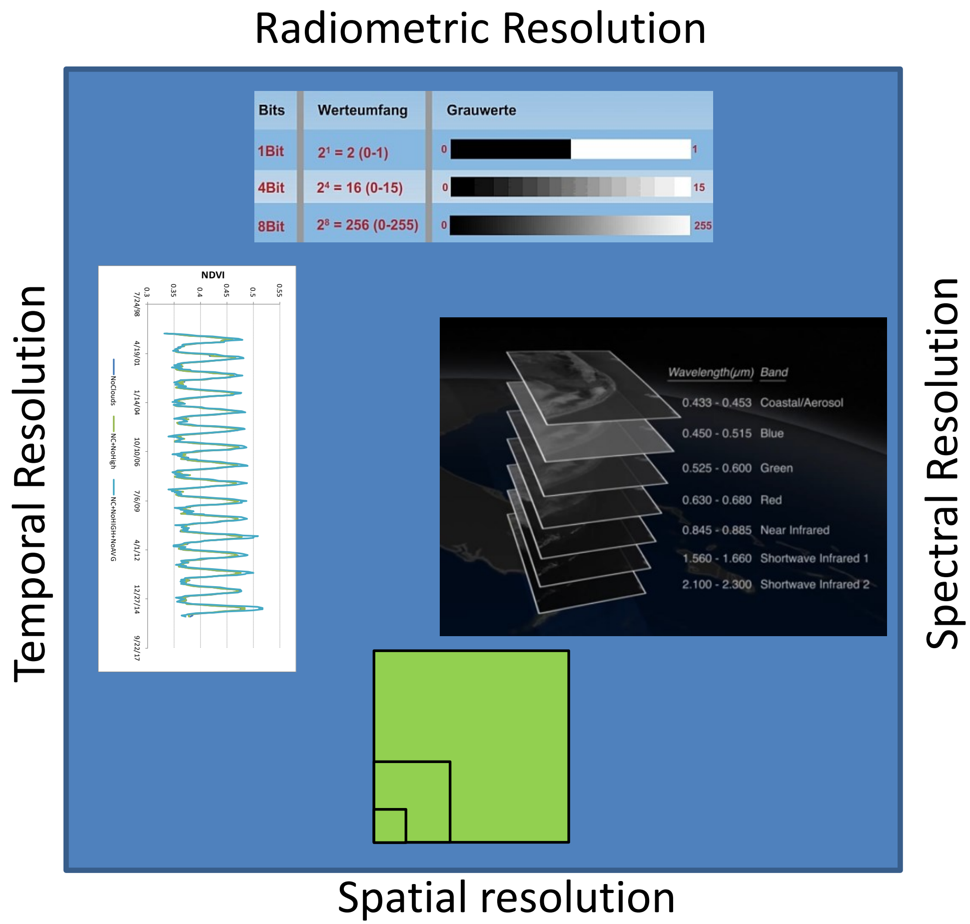
Remote Sensing Instruments

- A remote sensing instrument collects information about an object or phenomenon within the instantaneous-field-of-view (**IFOV**) of the sensor system without being in direct physical contact with it.
- The sensor is located on a suborbital or satellite platform.
- There are different satellite formation
  - **Geo**synchronous (with respect to a reference, sun rotation)
  - Geostationary (looks at almost the same spot always)
  - Hybrid



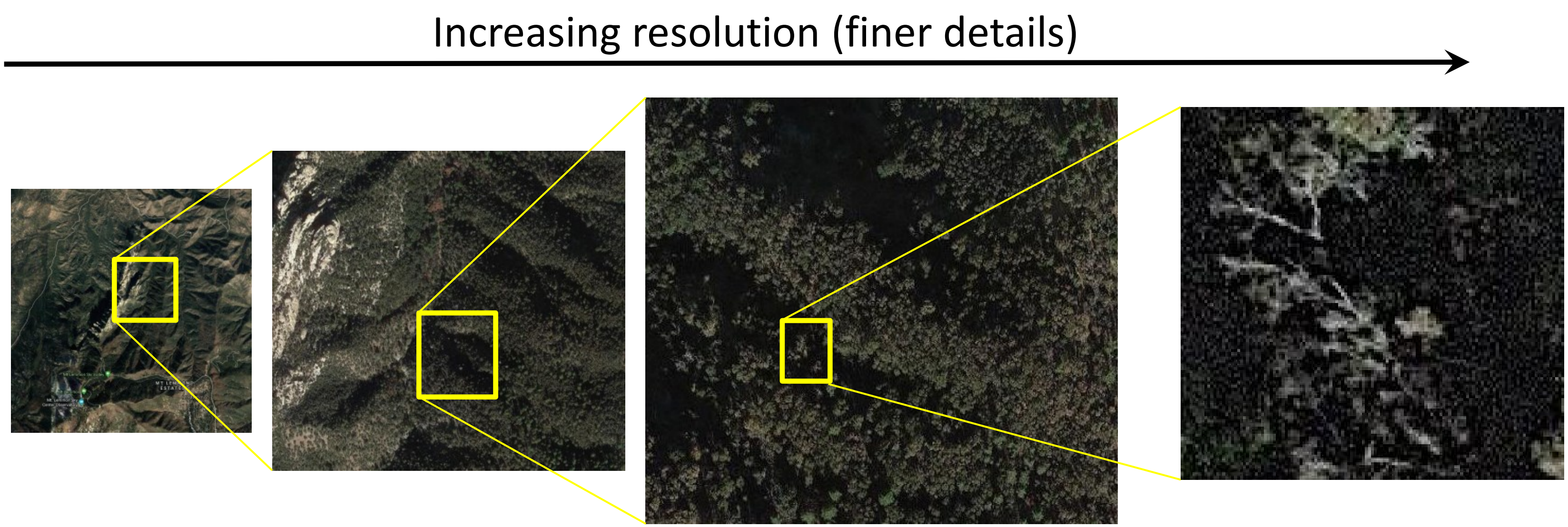
Key Concepts of Remote Sensing

- There are some extremely critical characteristics of a remote sensing systems. Need to always remember and keep them in perspective:
  - Spatial resolution
  - Spectral resolution
  - Radiometric resolution
  - Temporal resolution
- The **radiometric resolution** and the spatial resolution are key characteristics
- Lets review them one at a time



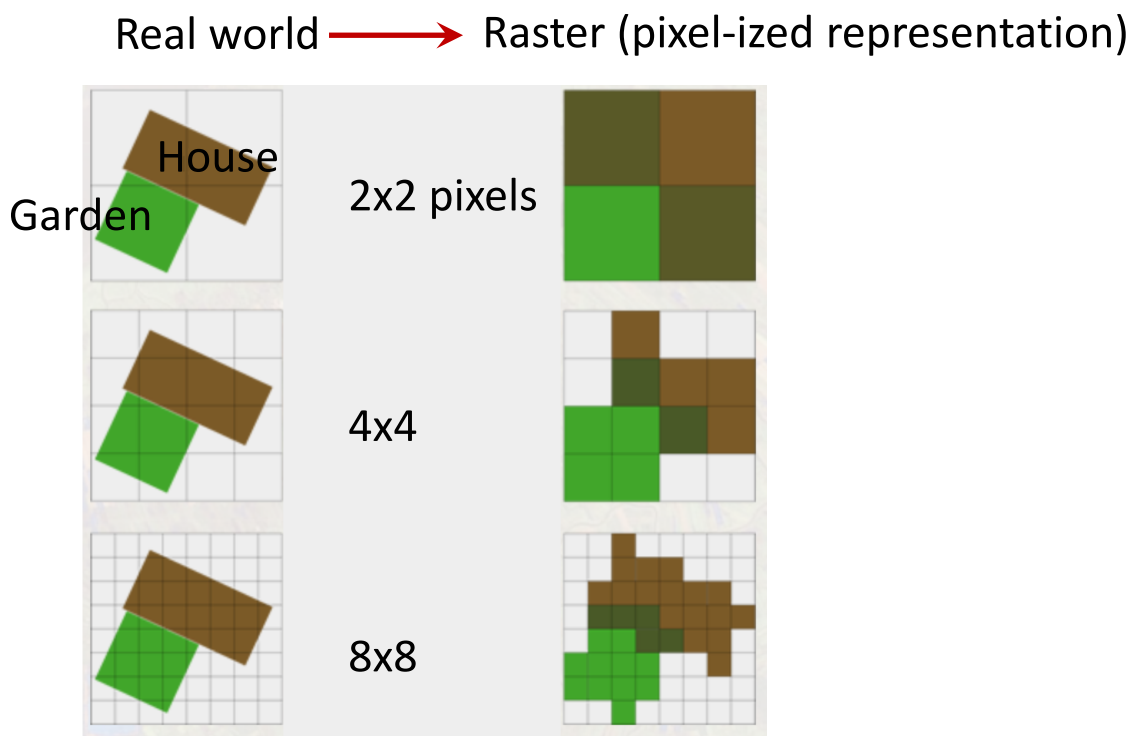
Spatial Resolution

- The **spatial resolution** signals the size of the section of the surface of the Earth which can be depicted in one pixel (one Digital Number – DN - value). Stated in cm/meters/km
- It describes the ability of a sensor to identify the smallest size detail of a pattern on an image. In other words, the distance between distinguishable patterns or objects in an image that can be separated from each other and is often expressed in meters.
  - There is a limit and a tradeoff here
  - Finer resolution means smaller coverage area and longer revisit time (monthly and even yearly)
  - Coarser resolution means larger coverage area and more frequent revisit (daily and even multiple times a day)
    - **Can you guess why?**
  - Everything within the pixel is aggregated (averaged).



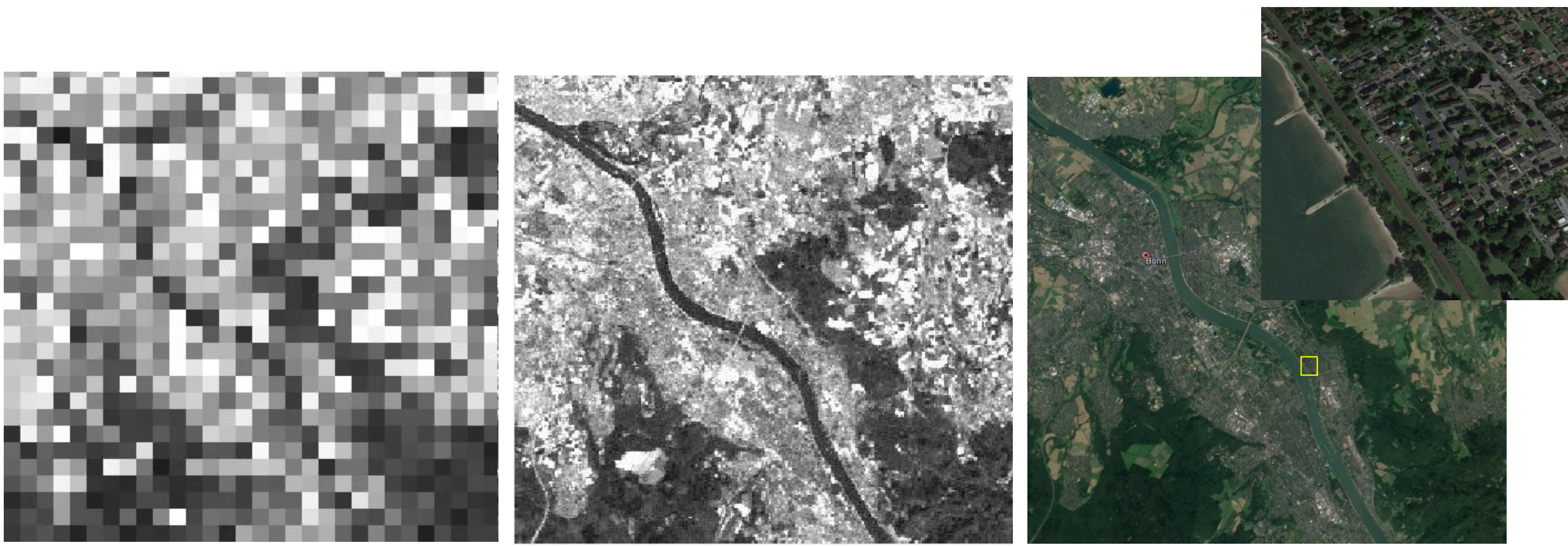
Spatial Resolution

- A **spectral remote sensing sensor** detects the reflected/emitted radiation of the Earth's surface and stores it as **digital numbers** (**DN**) in a **Raster (**matrix**)**.
- Each area detected constitutes a cell in a raster. And these raster cells are called **pixels**.
- The size of an area represented in a pixel depends on the capability/design of the sensor to detect details.



Low and High Spatial Resolution

- The ability of a remote sensing sensor to detect **details** is referred to as **spatial resolution**.
- The spatial resolution is defined in meters.
- The more pixels the more details can be observed, the higher the spatial resolution
- In the images below you can distinguish the higher spatial resolution of 30 m and a lower spatial resolution of 300 m.
- As resolution degrades (low) **much more different objects must be aggregated** in one pixel



Three images of the same location (Bonn, Germany) with Spatial resolution of 30 m and 300 m and 30m (© USGS/NASA Landsat Program).

Mixed Pixels – Spectral Mixing

- Objects that are close together must be represented by one pixel (one value).
- Such pixels are called **mixed pixels**.
- Depending on the sensor design and other factors the color (spectral) components of the pure objects are aggregated and result in mixed color/pixel (spectra), which is quite challenging to analyze.
- The lower the spatial resolution, the more mixing and the harder the analysis

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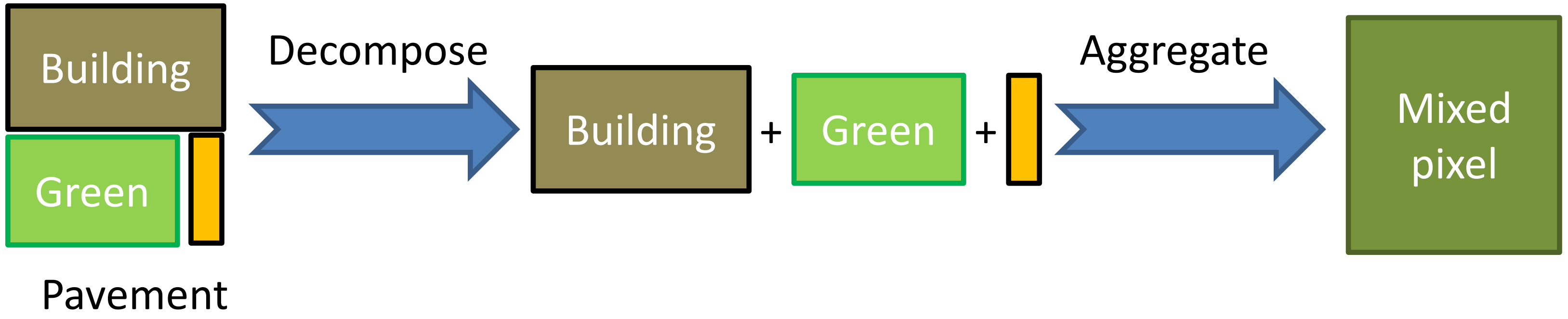
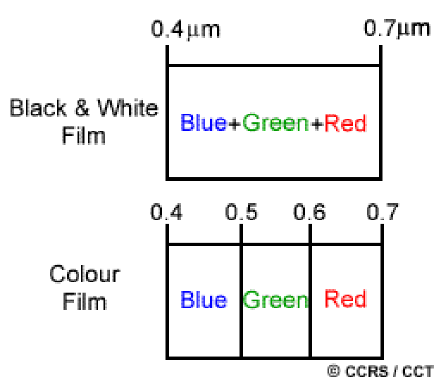


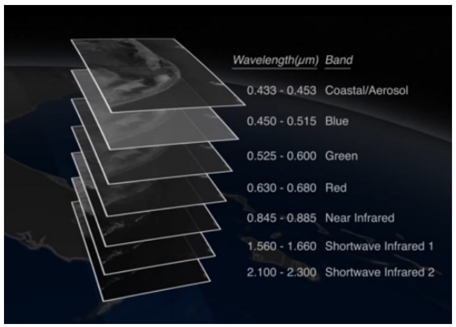
Why do Only Some Sensors Have a High Spatial Resolution?

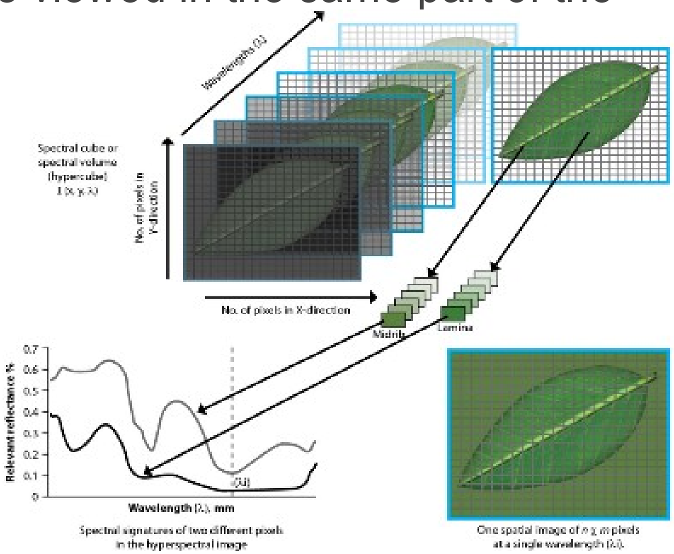
- It depends on the objectives and purposes of the remote sensing systems. The same sensor attached to an airplane will have a very high resolution (ex: 1 m, even few mm with drones these days), whereas, the satellite-based sensor will have a lower resolution (ex: 30 m).
- At the same time, the satellite-based sensor detects a wider area in one single image and circles the Earth completely in only few days. This is impossible for aircrafts!
- So the spatial resolution characteristics of spectral sensors are determined by the ratio of **extend** and **resolution**.
- If a maximized extend is required in order to capture greater areas, we have to lower our resolution
- Other considerations are the resulting data size, required supporting systems, distribution, redundancy, etc…
- Each remote sensing sensor produces ***raster image*** data. And each raster consists of raster cells, which are also referred to as pixels.
- The larger the pixel, the more objects on the surface of the earth are captured and the lower the spatial resolution.

Spectral Resolution

- **T**he sensitivity of a sensor to respond to a **<u>specific frequency/band range</u>** (for satellite and airborne sensors).
  - The frequency ranges include visible light, and non-visible light and electromagnetic radiation.
  - Objects on the ground can be identified by the different wavelengths reflected (interpreted as different colors) but the sensor used must be able to detect these wavelengths in order to see these features.
  - Visible, Infrared, Thermal, Monochromatic, Multispectral, and hyperspectral
- The smallest ‘slice’ of a band or portion of the EM spectrum in which the reflectance of a feature may be assigned a digital number
- Finest distinction that can be made between objects viewed in the same part of the EM spectrum.

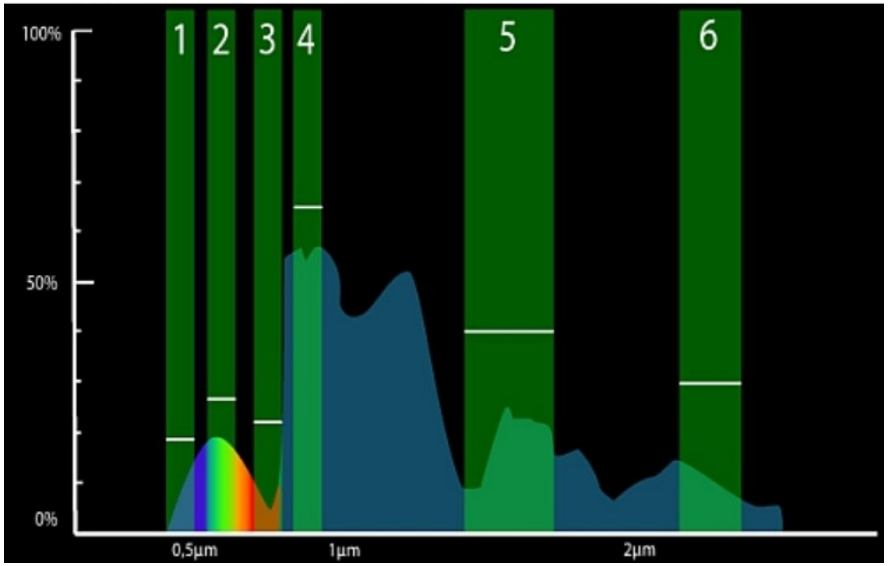






Spectral Resolution

- A Spectral sensor perceives objects as levels of grey.
- Each spectral band (wavelength) is detected separately and stored as light intensity.
- Blue light is stored in the blue band, green light in the green band and red light in the red band, etc.
- The higher the number of bands of a remote sensing sensor, the higher its spectral resolution.
- Ex: Landsat or OLI has multiple spectral bands (7+ bands)
  - Usually composed of the visible light, infrared light, and thermal radiation.



Spectral Resolution

- When using several separate bands for observing the Earth these techniques are called **multispectral remote sensing**.
- There are sensors with 200-400+ bands as well. Called **hyperspectral**.
- Two fundamental conditions have to be considered in order to determine which spectral bands are appropriate for a particular application/sensor:
  - The **atmospheric window** and,
  - The **spectral signature** of the object in question.

TM Spectral bands

Landsat 1-5 Multispectral Scanner (MSS)

Landsat 1-3	Landsat 4-5	Wavelength (micrometers)	Resolution (meters)
Band 4	Band 1	0.5-0.6	60
Band 5	Band 2	0.6-0.7	60
Band 6	Band 3	0.7-0.8	60
Band 7	Band 4	0.8-1.1	60

Landsat 4-5 Thematic Mapper (TM)

Landsat 4-5	Wavelenth (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120 (30)
Band 7	2.08-2.35	30

Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

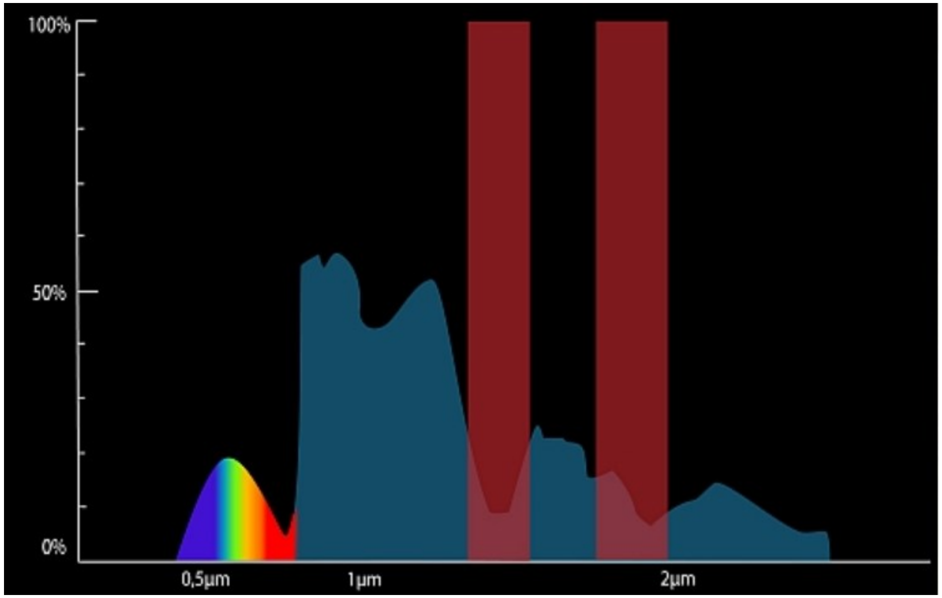
Landsat 7	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.77-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	60 (30)
Band 7	2.09-2.35	30
Band 8	.52-.90	15

Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

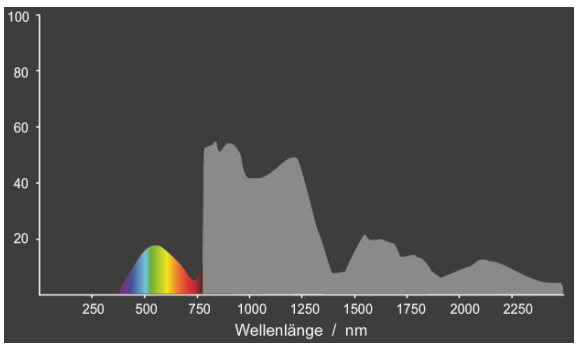
Atmospheric Windows

- Spectral sensors can only store the detect parts of the electromagnetic radiation scattered back from the Earth surface that can pass the atmosphere.
- The Earth's atmosphere contains gases (Water, Ozone, Nitrogen, CO2, etc.) and small particles like smoke, ice crystals, water drops, dust, etc.… These so-called **aerosols absorb** and **scatter** all or some parts of the electromagnetic spectrum.
- So regions of the spectrum that are absorbed by the atmosphere are called **absorption bands**.
- Wavelengths getting through the atmosphere to the sensor are called **atmospheric window**.
- The figure below depicts how intense the solar radiation is per wavelength range.
- The intensity of the reflected **radiation energy** decreases the closer we get to the long-wave range of the electromagnetic spectrum.



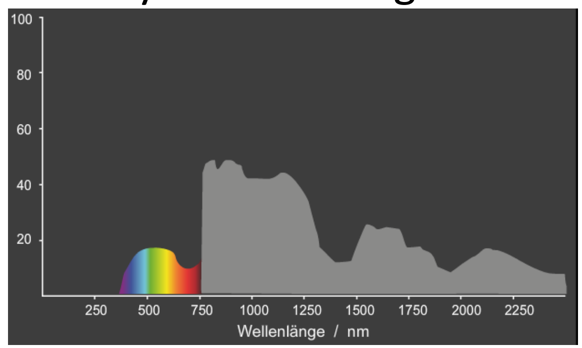
Spectral Signature

- Besides atmospheric windows, the selection of spectral bands must consider the reflection characteristics (spectral signature) of objects on the Earth's surface.
- Different object on the surface of the Earth reflect differently in the various parts of the electromagnetic spectrum.

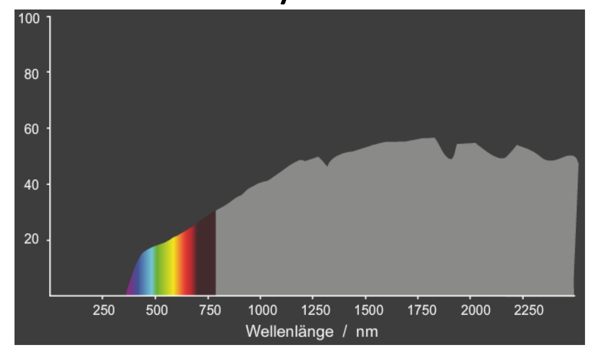


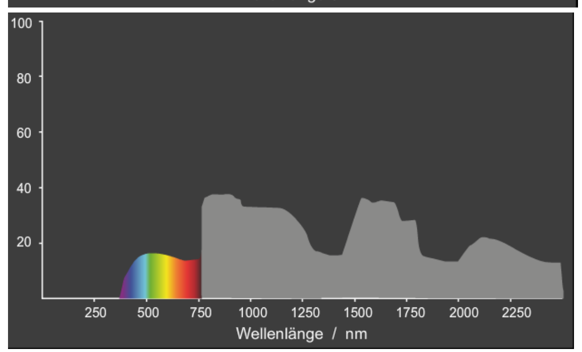
Healthy Active Vegetation

Mildly Stressed Vegetation

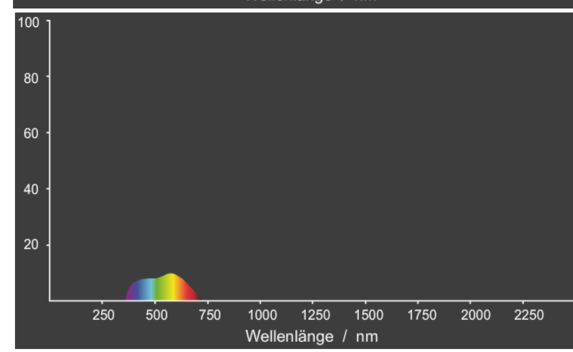


Dry soil





Heavily Stressed Vegetation

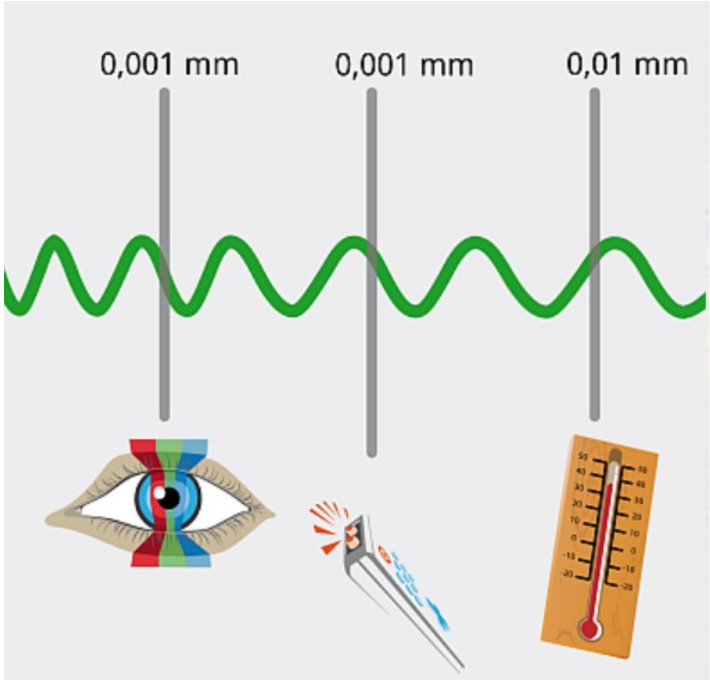


Water

- Dry soil reflects highly in the infrared region, whereas water reflects in the visible range of light only (blue or color of mud). All objects on the surface of the Earth have a specific **spectral signature or fingerprint** that results from its ability to absorption and reflect light.

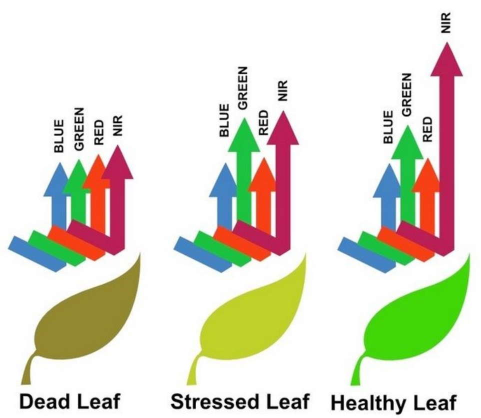
Invisible Infrared

- The visual light(VIS) as well as the **infrared range** are the most important for land multispectral remote sensing.
- The infrared range follows the visible range (0.3-0.7μm) in the electromagnetic spectrum and its wavelengths are between 0.7 und 1000+ micrometer.
- Infrared radiation is **invisible to the human eye** and is divided into near (NIR), short-wave (SIR) mid-wave (MIR), long-wave (LIR) and thermal (TIR) infrared.

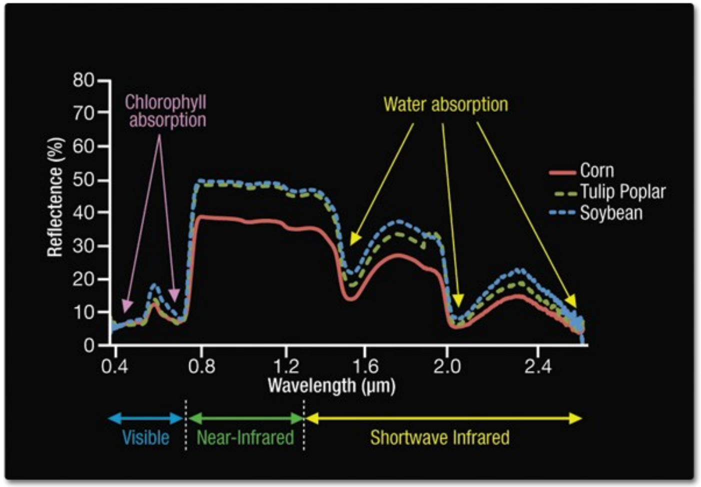


Plant Spectra

- The reflection characteristics of **vegetation** are interesting.
- Active green plants reflect green light greatly, red and blue light partially.
- This is caused by **chlorophyll** which uses the blue and red range of light for **photosynthesis** but reflects the green light.
- The reflection curve has a steep slope in the infrared range and is steady on a high level until it drops down in the range of mid-infrared because of absorption due to the high moisture content in green vegetation.
- This is the so-called **red edge**?
- This jump in signature is due to the plant cell walls which reflect infrared light within the cells several times. Due to the high reflection values in the infrared range we see that plants (much chlorophyll and stable cell walls) are prominent in the infrared band of satellite images.
- If humans were able to see infrared light, leaves would not be green but infrared to us.

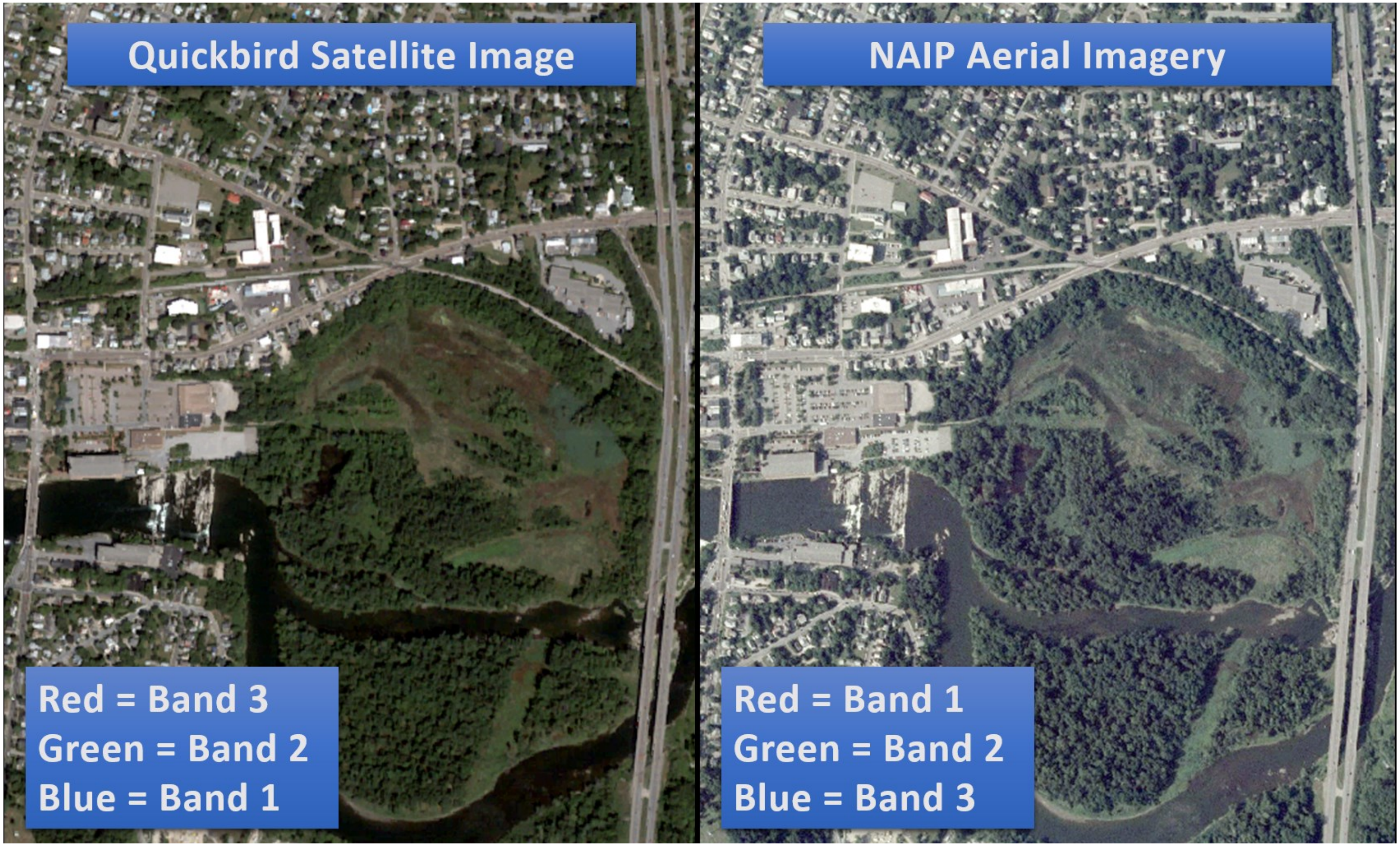


The basic principle of NDVI relies on the fact that, due the their spongy layers found on their backsides, leaves reflect a lot of light in the near infrared, in stark contrast with most non-plant object. When the plant becomes dehydrated or stressed, the spongy layer collapses and the leaves reflect less NIR light, but the same amount in the visible range. Thus, mathematically combining these two signals can help differentiate plant from non-plant and healthy plant from sickly plant.



Spectral Resolution

- Same area by different sensors with different spectral resolutions

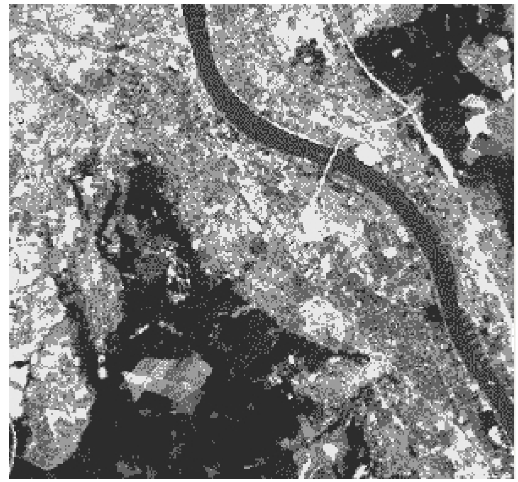


Radiometric Resolution

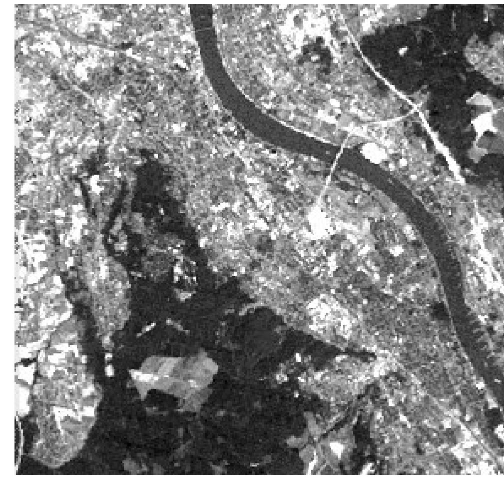
- **O**ften called contrast.
  - It describes the ability of the sensor to measure the signal strength (reflectance) or brightness of an object. The more sensitive a sensor is to the reflectance of an object as compared to its surroundings, the smaller an object that can be detected and identified.
  - The ability of the system to discriminate very slight differences in the energy being measured (reflected or emitted)
  - The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in the reflected or emitted energy
- The radiometric resolution of image data in remote sensing stands for the ability of the sensor to distinguish different grey-scale values. It is measured in bit. The more bit an image has, the more grey-scale values can be stored, and, thus, more differences in the reflection on the land surfaces can be spotted.
- The radiometric resolution stands for the ability of a digital sensor to distinguish between **grey-scale values** while acquiring an image.
  - Humans see the nature in color. However, a satellite perceives different wavelengths in different intensities only.
  - A sensor can distinguish between bright and dark with a great deal of precision.
  - A spectral image is not less than a **raster** consisting of different grey-scale values (at the respective band).
- The next slide contains two spectral images of Bonn: The first has a radiometric resolution of 2 and the second has a radiometric resolution of 8 bit. It becomes clear that surfaces can be distinguished much better in the 8-bit image than in the 2-bit image.

Radiometric Resolution

The surfaces can be distinguished much better with a higher radiometric (bit) resolution



2 Bit



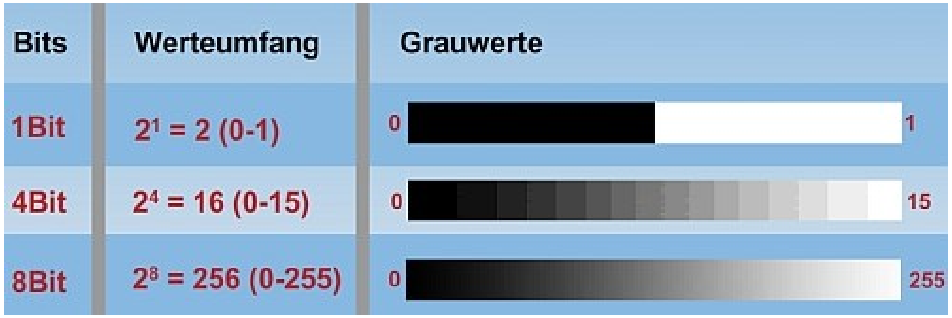
8 Bit

Temporal Resolution

- **T**his depends on many factors
  - How long it takes for a satellite to return to (approximately) the same location in space
  - The swath of the sensor (related to its 'footprint'), and
  - Whether or not the sensor can be directed off-nadir.
  - This is formally known as the 'revisit period'
    - Ex: MODIS aboard Terra and Aqua revisit is 16 days (same for VIIRS aboard S-NPP)
- Image acquired by remote sensing sensors do not only differ with regard to the spatial, radiometric and spectral resolutions: The so-called **temporal resolution** is also very important.
- The temporal resolution provides information on the time between the acquisitions of two images of the same area. The higher the temporal resolution, the shorter the distance of time between the acquisitions of images.
- Many satellites have a temporal resolution of about 14-16 days. But there are also satellites with a very high temporal resolution capable of acquiring images of the same area every 15 minutes. That is because satellite sensors with a high temporal resolution such as weather satellites are **geostationary** satellite sensors.

What is a BIT then?

- In **remote sensing**, a bit stands for the number of grey-scale values a spectral sensor can tell apart (separate).
- The greater the bit number, the greater the number of grey-scale values a spectral sensor can distinguish, and therefore, the higher the radiometric resolution of a spectral sensor.
- One bit stands for a sensor that knows only **black** and **white**.
- 2 bit equals 4 grey-scale values and
- 4 bit equals 16 values.
  - The equation is as follows:
    - 2^{bit} = Number of grey-scale values
  - 16 bit? How many values?
    - 65536



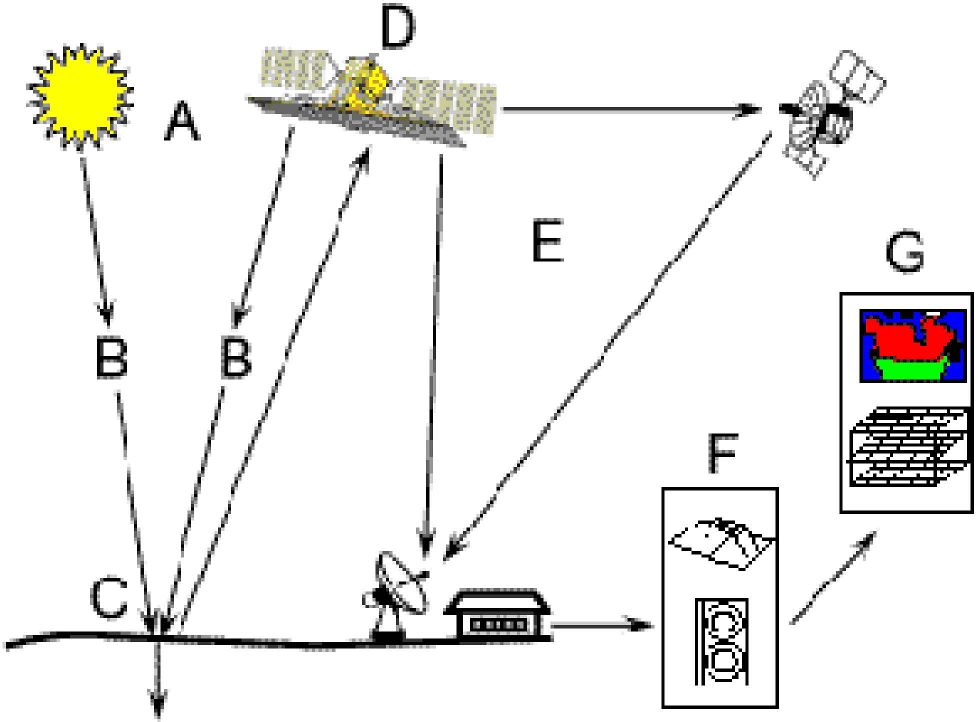
Bits	Werteumfang	Grauwerte
1Bit	$2^1 = 2$ (0-1)	0 … 1
4Bit	$2^4 = 16$ (0-15)	0 … 15
8Bit	$2^8 = 256$ (0-255)	0 … 255

Remote Sensing System

- *"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."*
- **The process** involves an interaction between incident radiation and the targets of interest.
- Remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

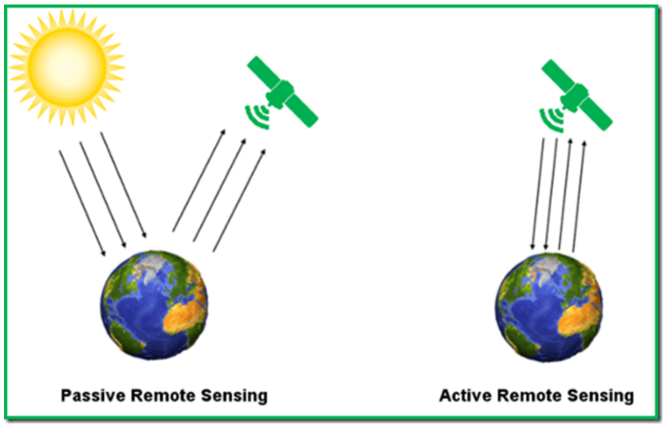
Remote Sensing System

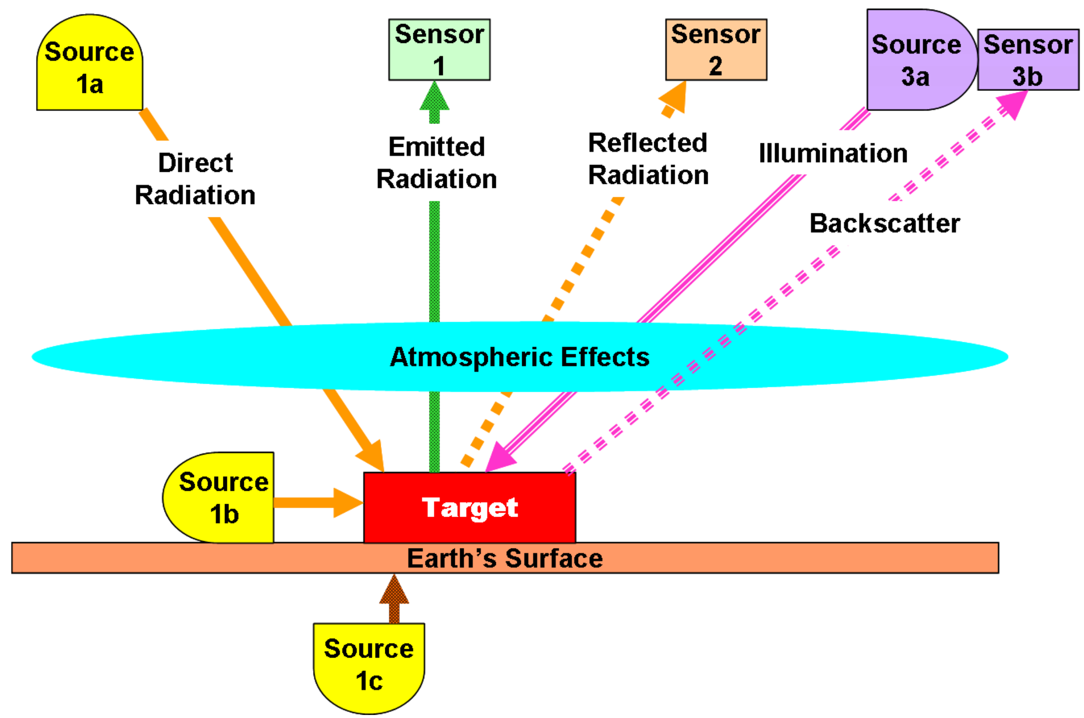
1. Energy Source or Illumination (A)
2. Radiation and the Atmosphere (B
3. Interaction with the Target (C)
4. Recording of Energy by the Sensor (D)
5. Transmission, Reception, and Processing (E)
6. Interpretation and Analysis (F)
7. Application (G)



Energy Source or Illumination (A)

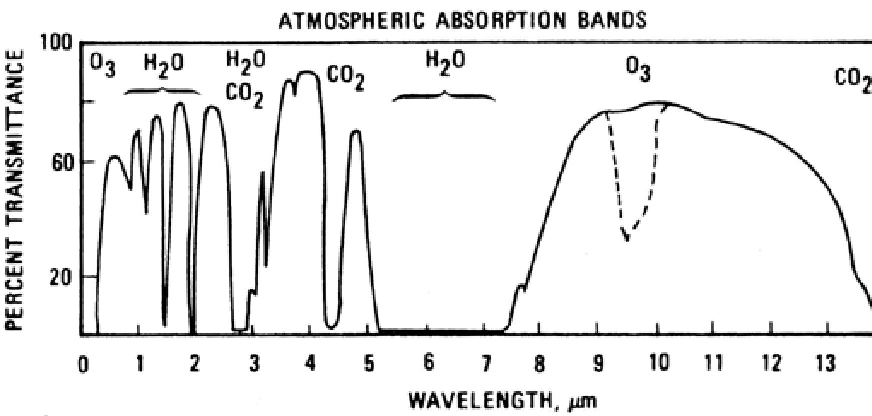
- The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
- There are two types: Active & Passive

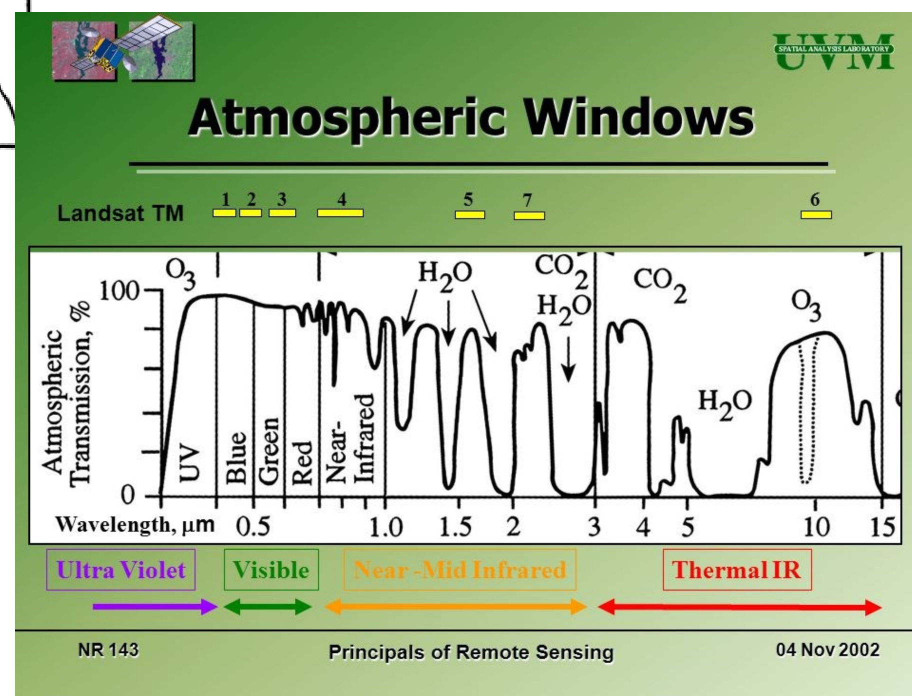




Radiation and the Atmosphere (B)

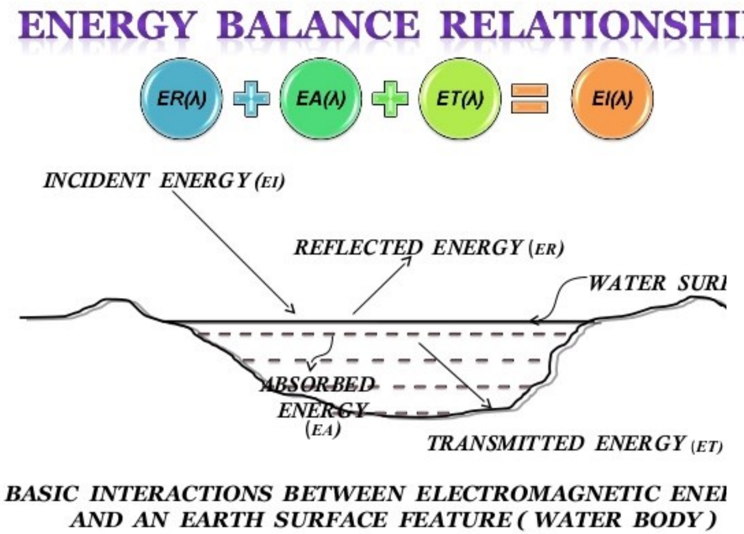
- **As** the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through.
- This interaction may take place a second time as the energy travels from the target to the sensor.

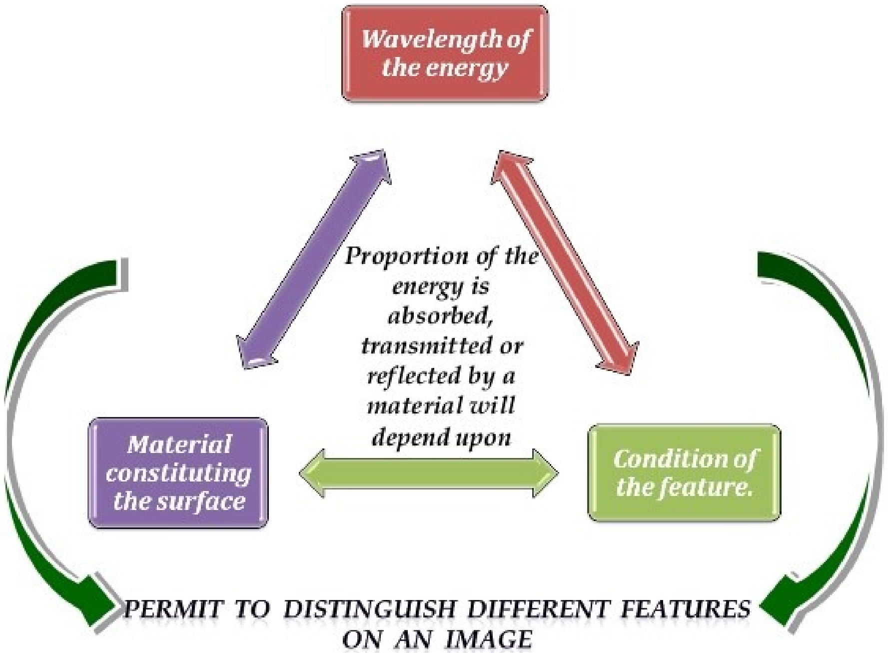




Interaction with the Target (C)

- **O**nce the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.





Recording of Energy by the Sensor (D)

- After the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation in a digital format (Digital Number = DN).
- Uses an Analog to Digital encoder

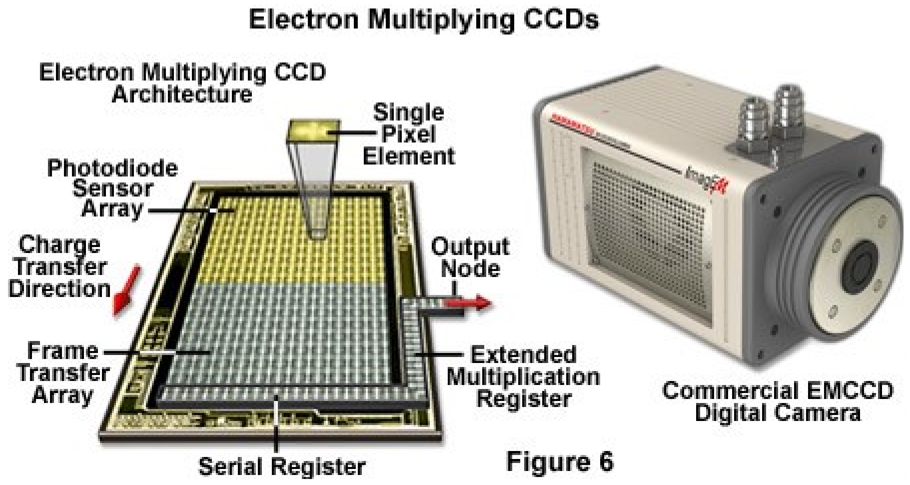
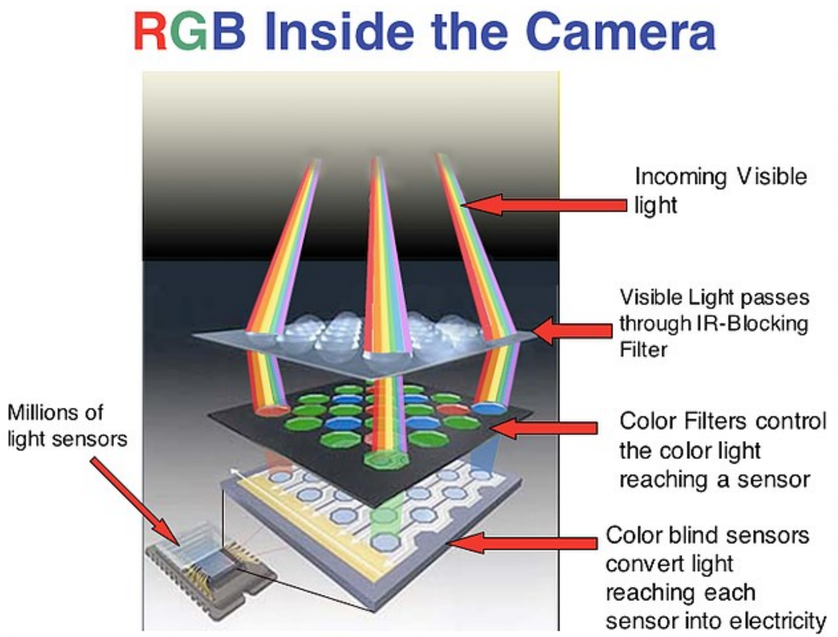


Figure 6

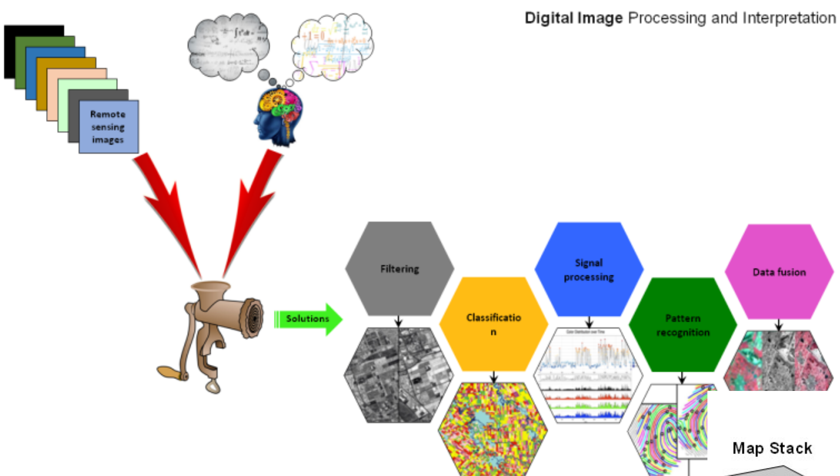


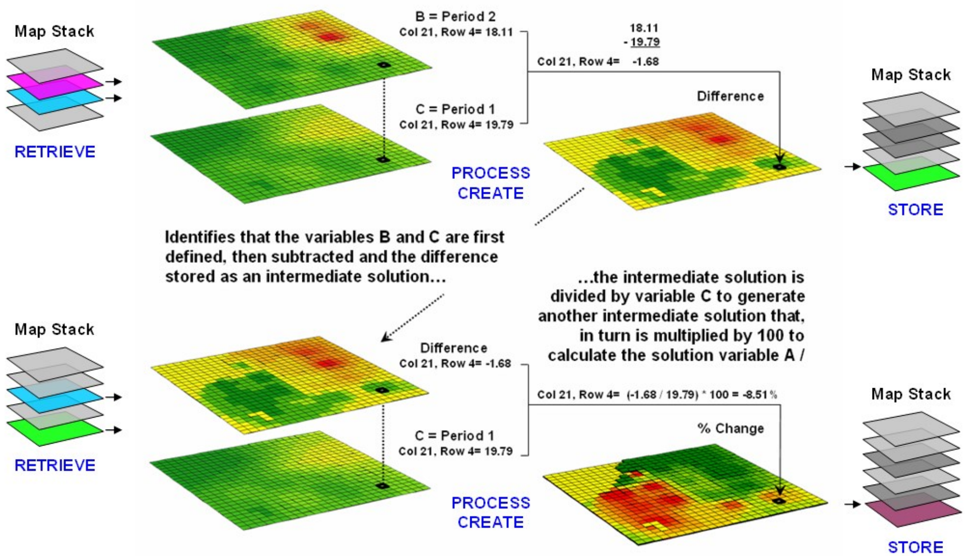
Transmission, Reception, and Processing (E)

- **T**he energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

Interpretation and Analysis (F)

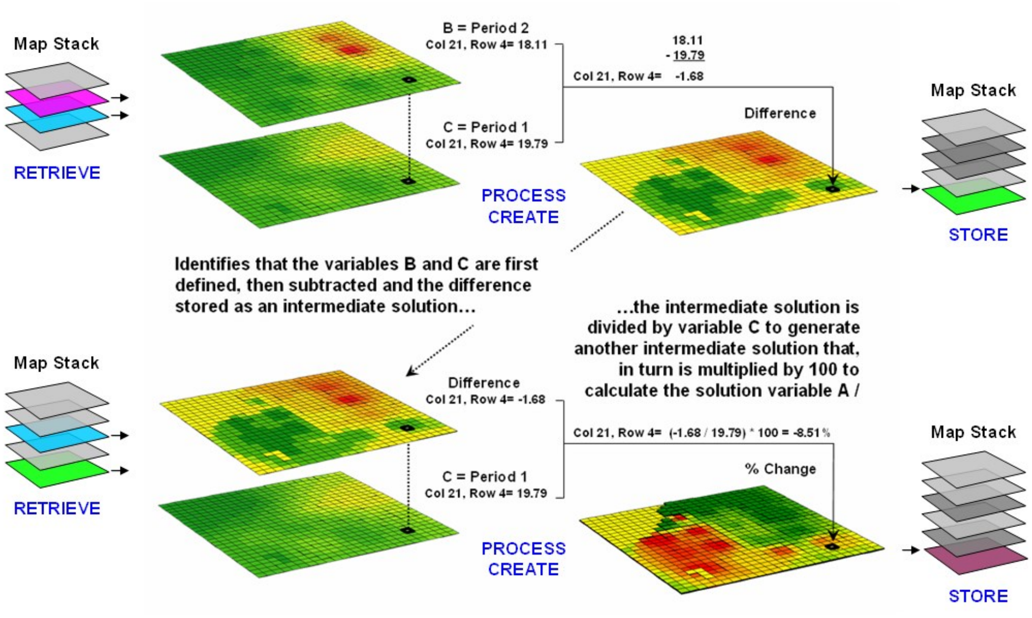
- The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.





Application (G)

- **T**he final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.
- These seven elements comprise the remote sensing process from beginning to end.



Homework #2

- Can you search the net for info on the Operational Land Imager (OLI) and find the 4 basic characteristics?
  - Spatial
  - Radiometric
  - Spectral
  - Temporal
  - Can you find the most ‘recent’ AZ/Tucson image from this sensor?

backup