THE UNIVERSITY OF ARIZONA

BE/BAT 485/585

Remote Sensing Data and Methods

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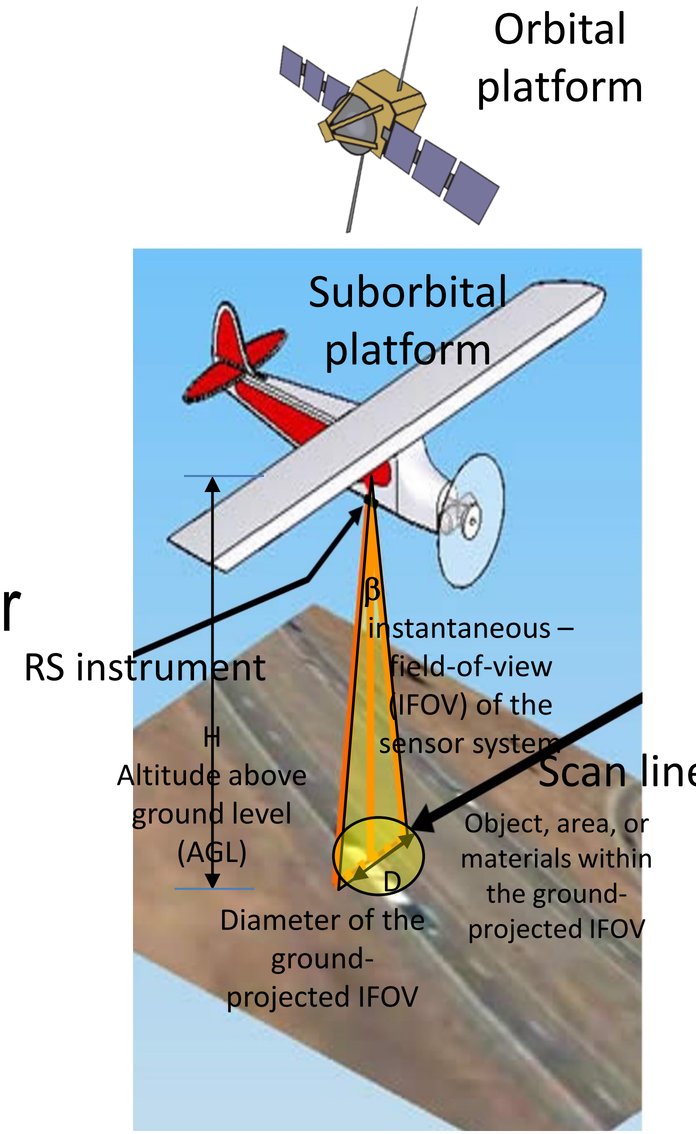
vegetation index & phenology Lab.

...Understanding a piece of the Earth system

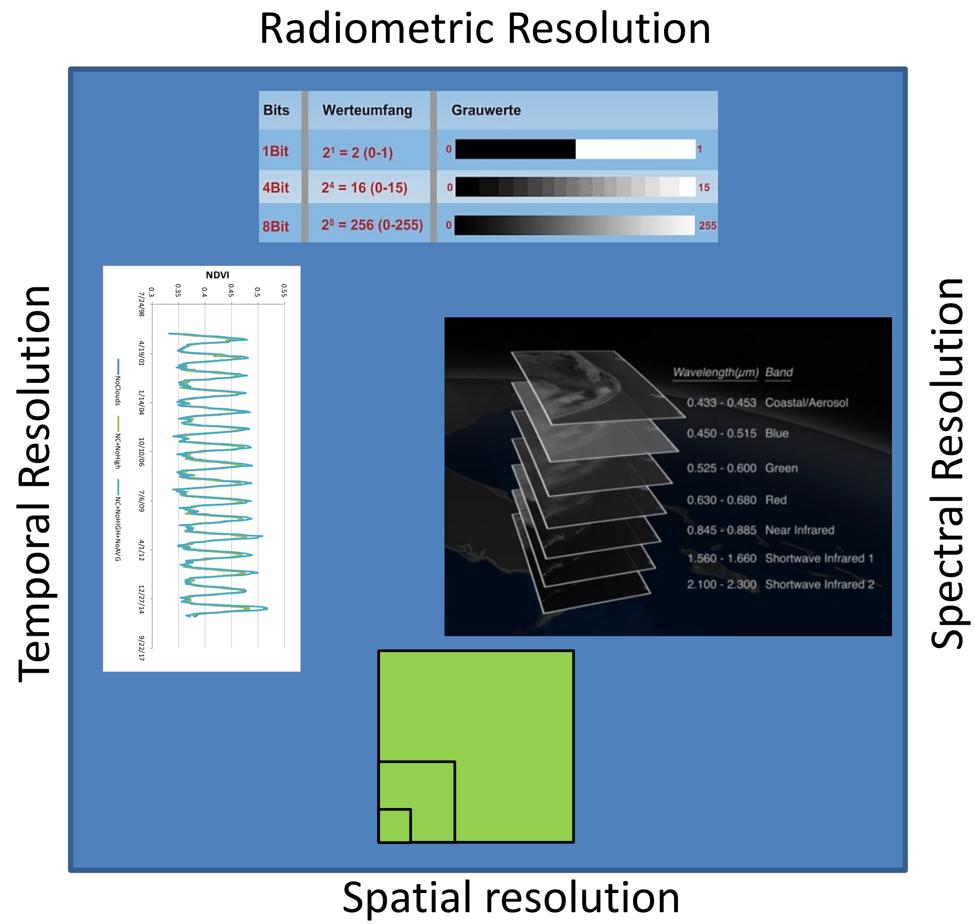
Remote Sensing Instruments

- 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



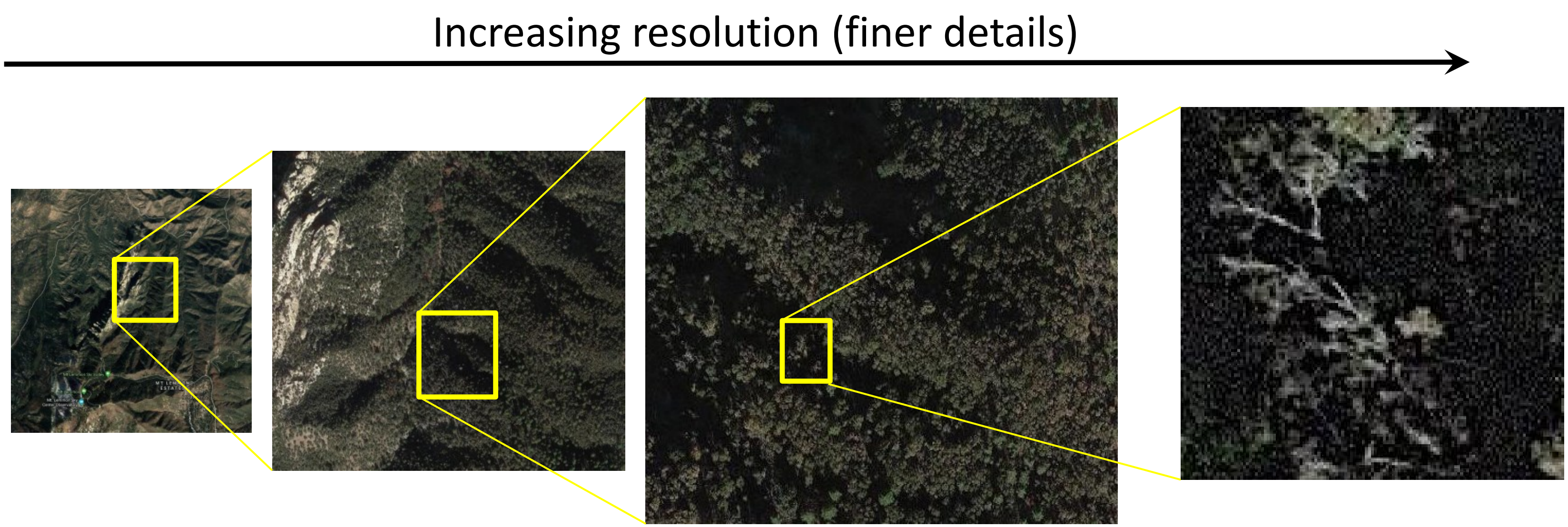
Key Concepts of Remote Sensing

- There are some critical characteristics of a remote sensing system.
- 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
- Let's review them one at a time



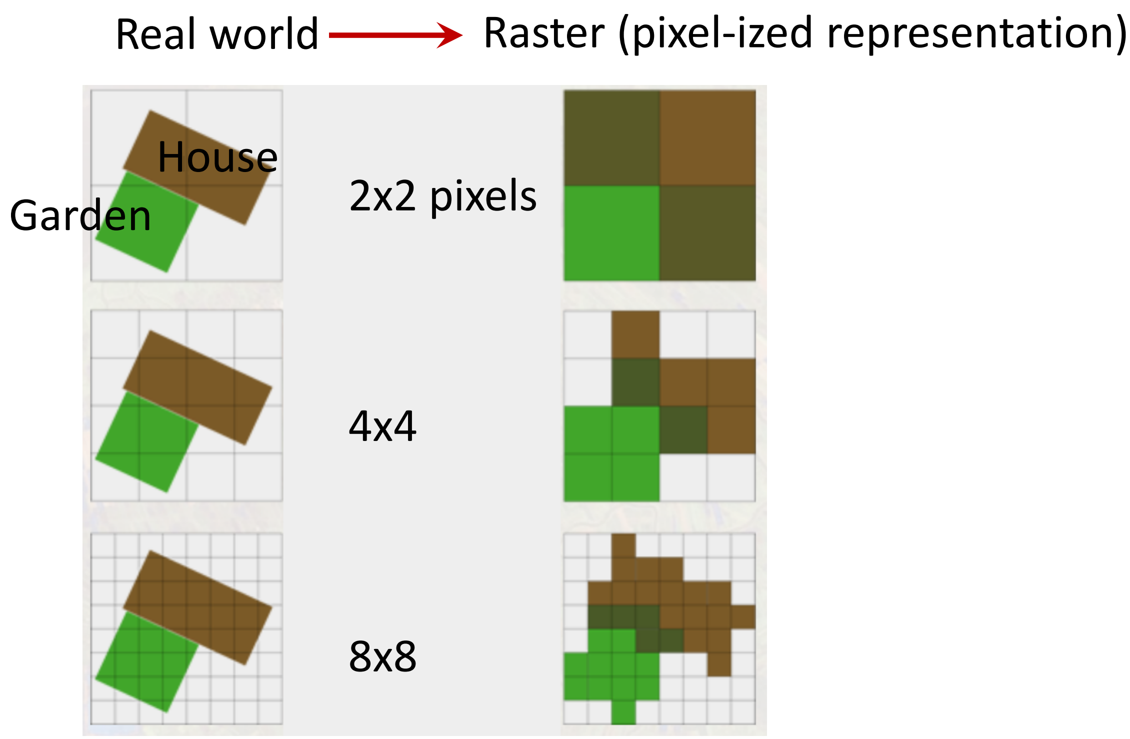
Spatial Resolution

- 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).



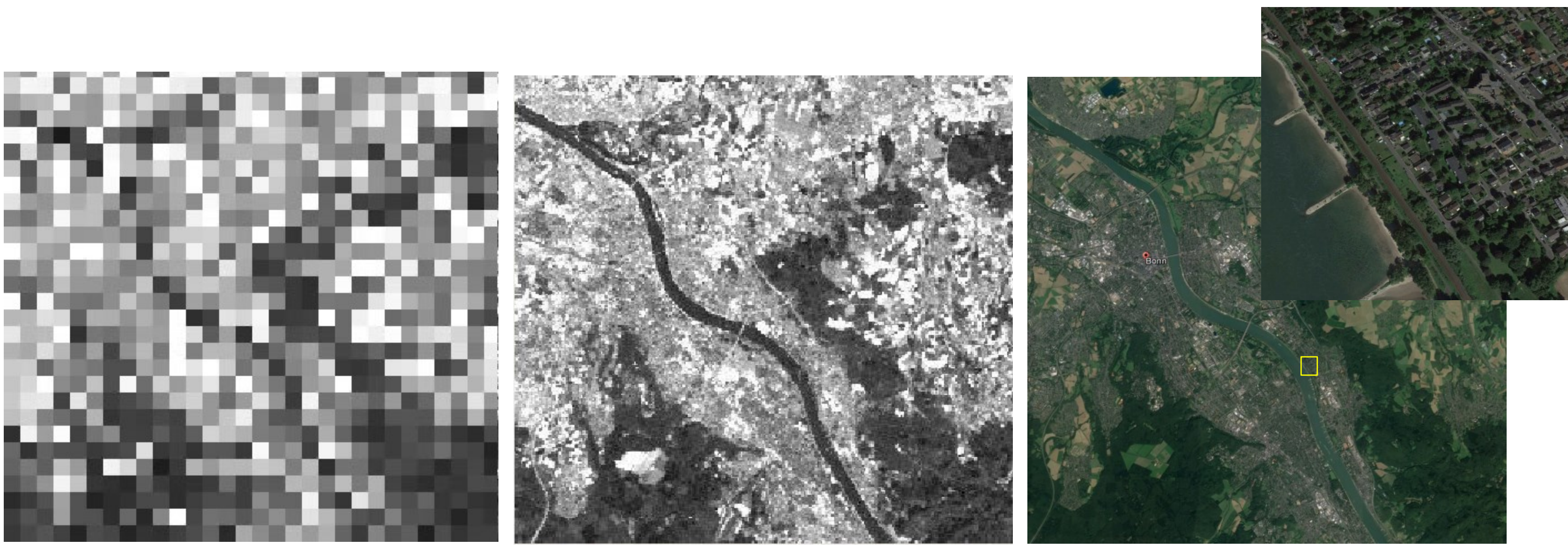
Spatial Resolution

- 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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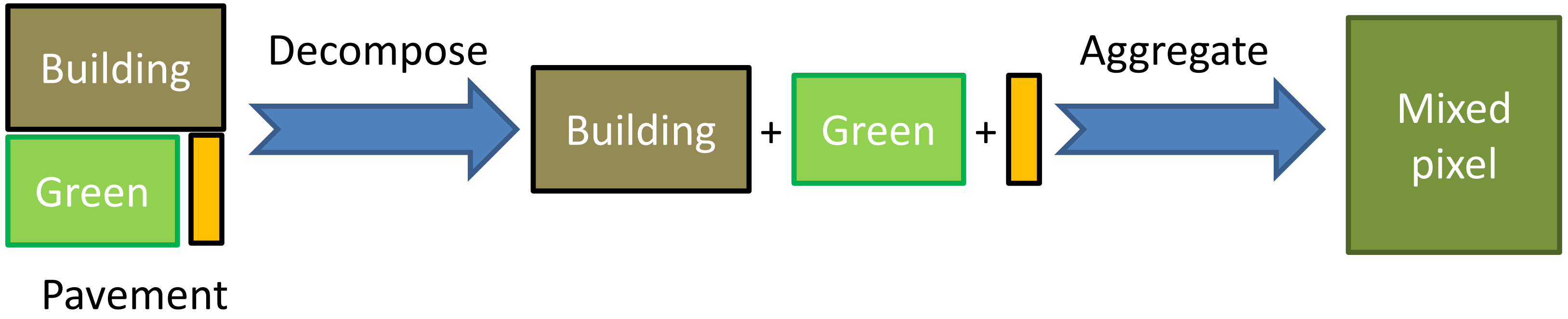
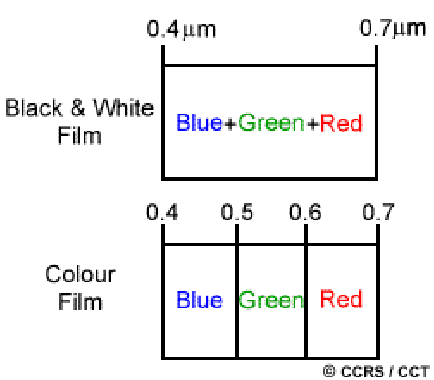


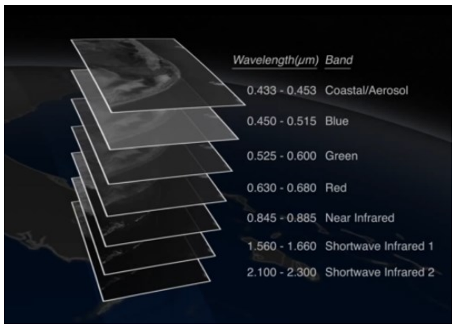
Why do Only Some Sensors Have a High Spatial Resolution?

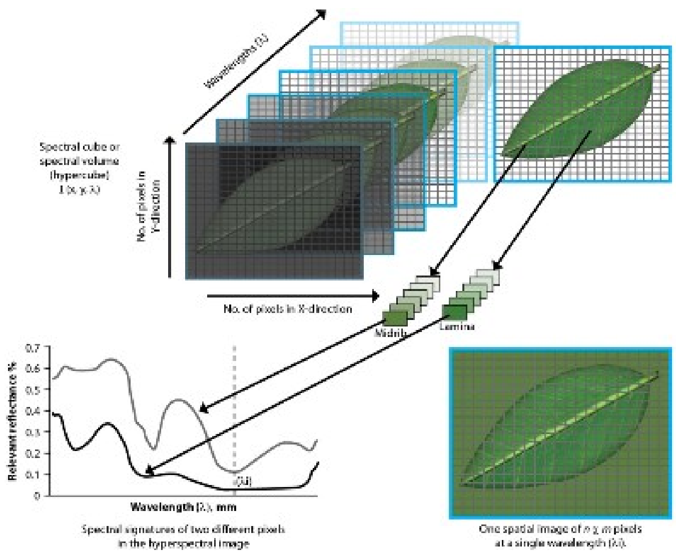
- It depends on the objectives and purposes of the remote sensing systems. The same sensor attached to an airplane will have a very high resolution (ex: 1 m, even few mm with drones these days), whereas, the satellite-based sensor will have a lower resolution (ex: 30 m).
- At the same time, the satellite-based 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

- The sensitivity of a sensor to respond to a specific frequency/band range (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.

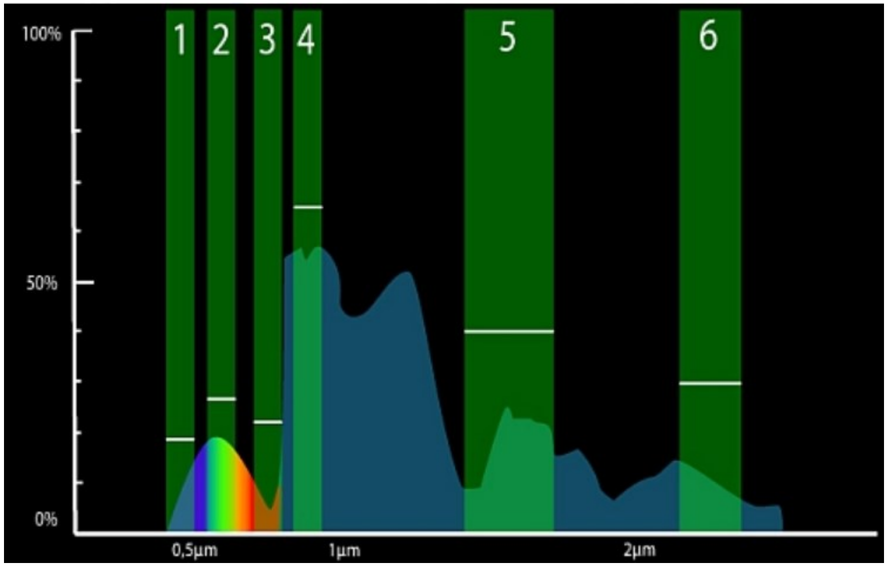






Spectral Resolution

- 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). MODIS has 36 bands (7 for land)
  - 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+)

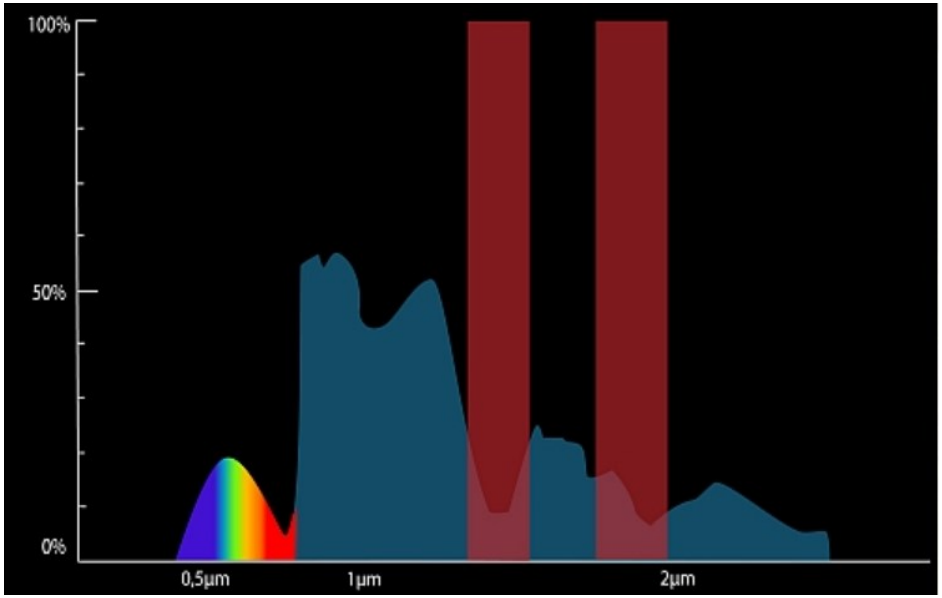
Landsat 7	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.77-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	60 (30)
Band 7	2.09-2.35	30
Band 8	.52-.90	15

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

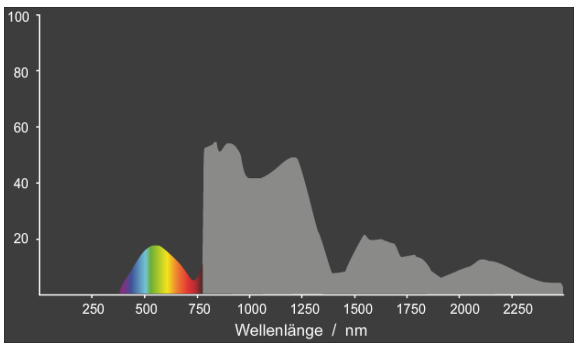
Atmospheric Windows

- 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.



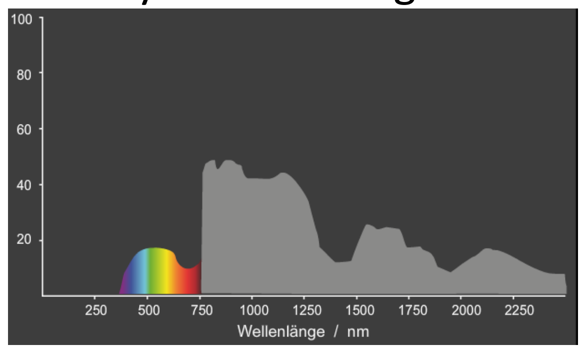
Spectral Signature

- 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.

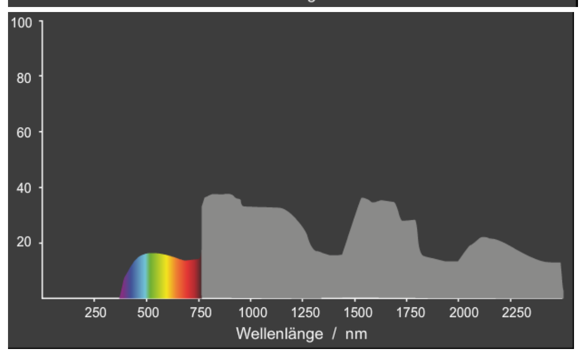


Healthy Active Vegetation

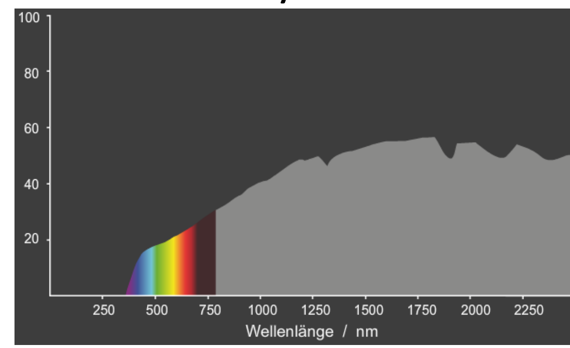
Mildly Stressed Vegetation

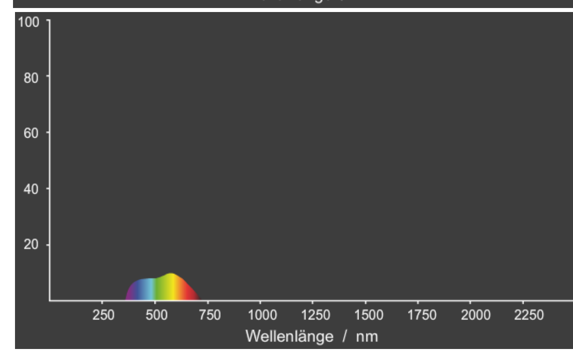


Heavily Stressed Vegetation



Dry soil



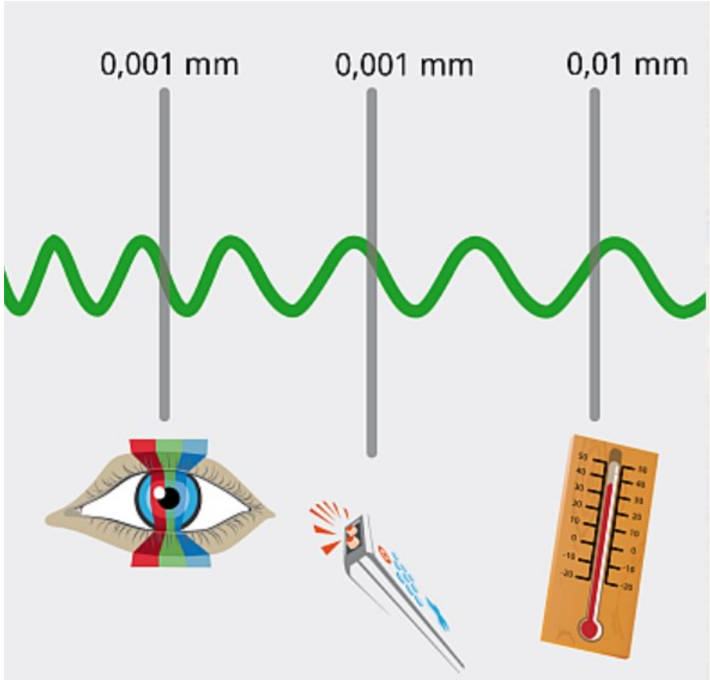


Water

- 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.

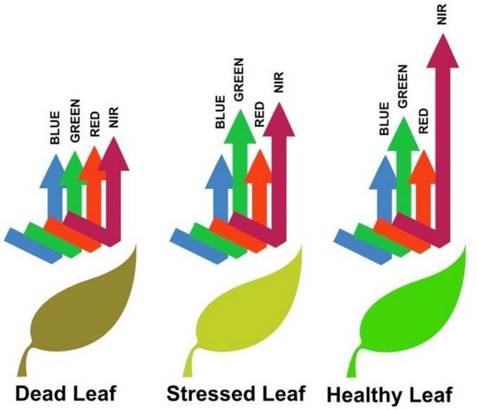
Invisible Infrared

- 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.

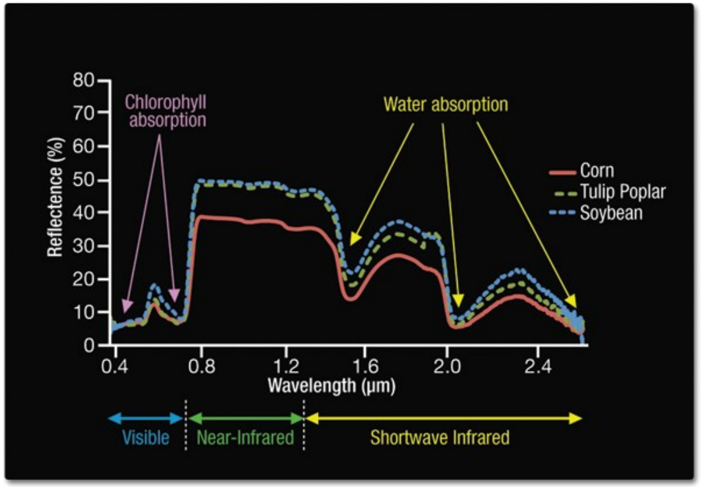


Plant Spectra

- 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.

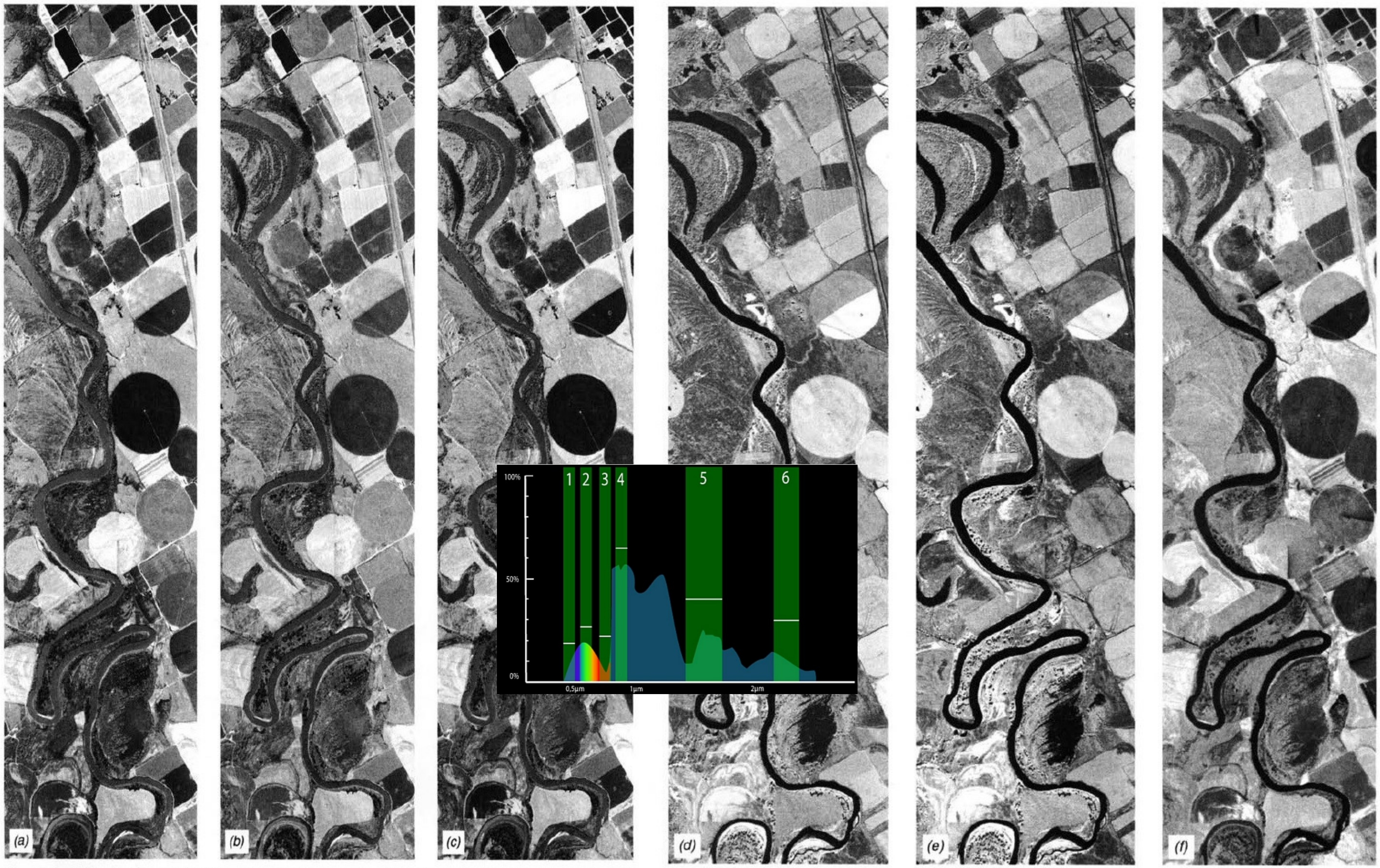


The basic principle of NDVI relies on the fact that, due the their spongy layers found on their backsides, leaves reflect a lot of light in the near infrared, in stark contrast with most non-plant object. When the plant becomes dehydrated or stressed, the spongy layer collapses and the leaves reflect 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

Blue | Green | Red | near IR | near IR | thermal IR



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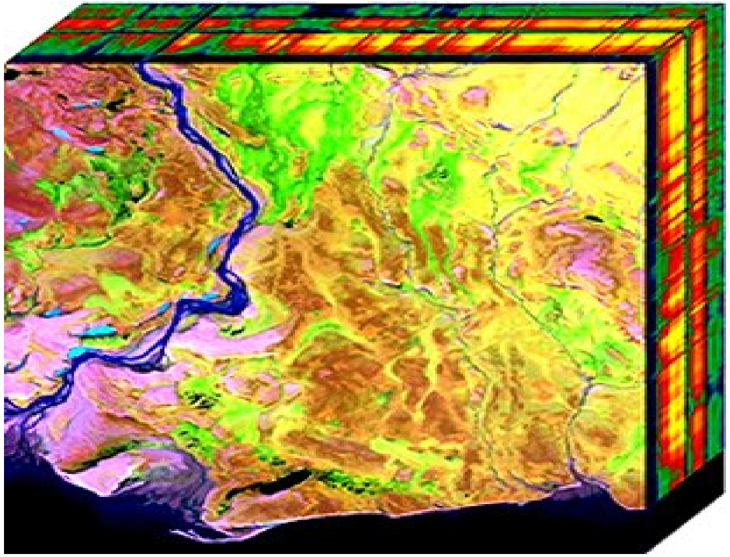
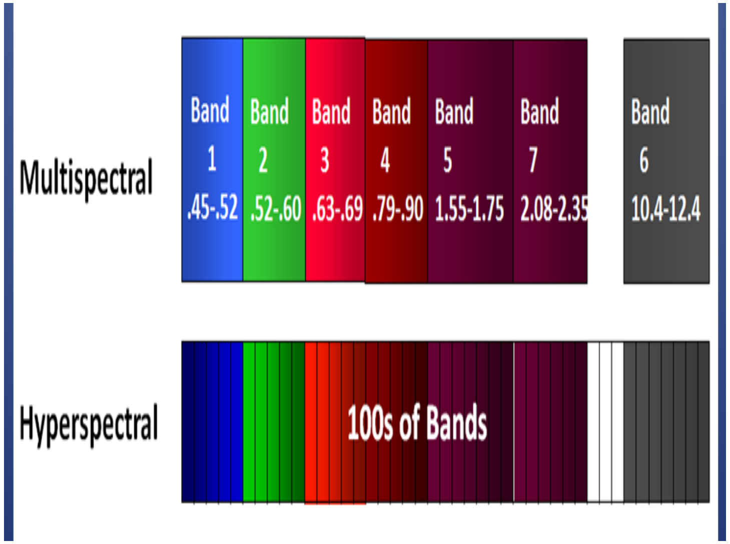
MS vs. Hyperspectral

- Difference between multispectral & hyperspectral sensing is:
  - Number of Bands
  - Narrowness of the Bands
- Multispectral data: 5-10 bands of large bandwidths (70-400 nm).
- Hyperspectral data: 100-400+ bands of narrow bandwidths (5-10 nm).





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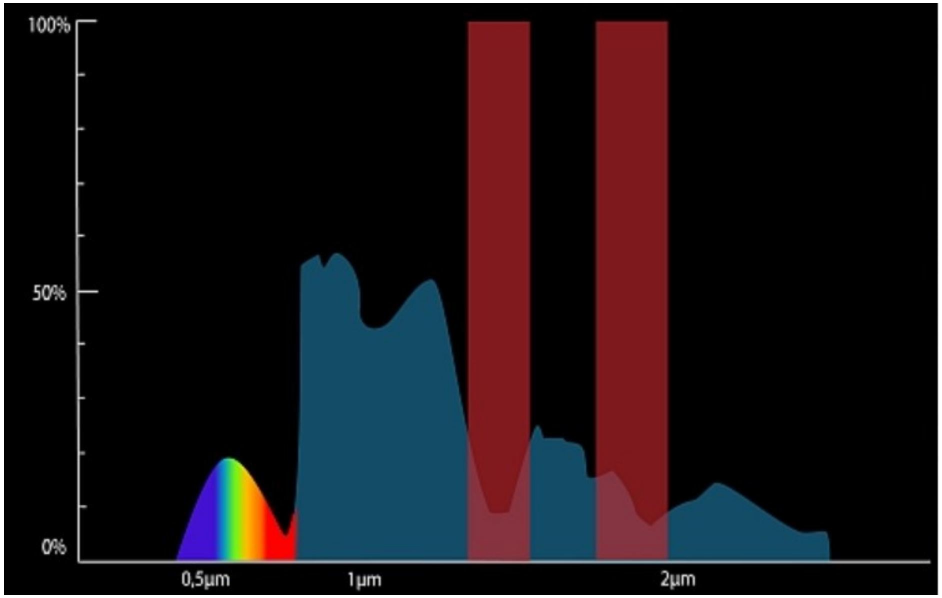

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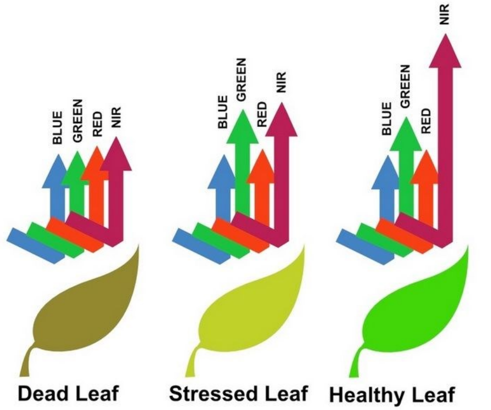

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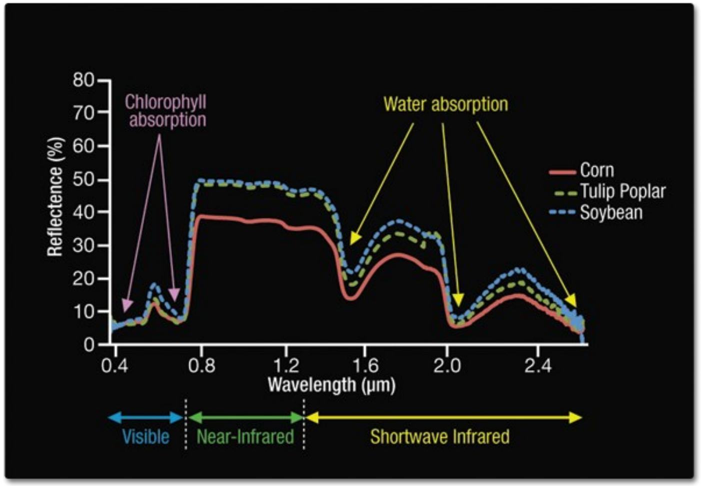
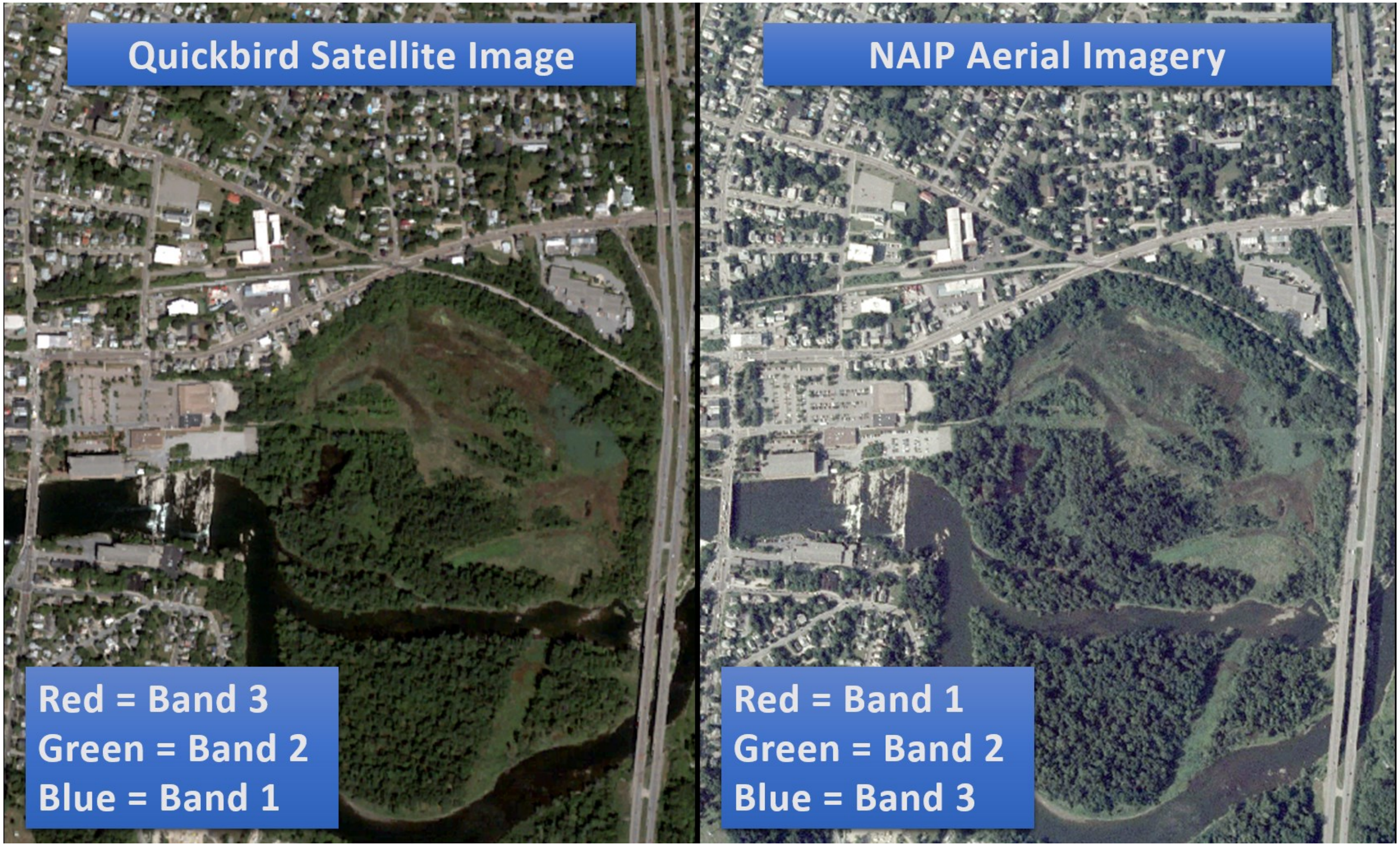


Spectral Resolution

- Same area by different sensors with different spectral resolutions



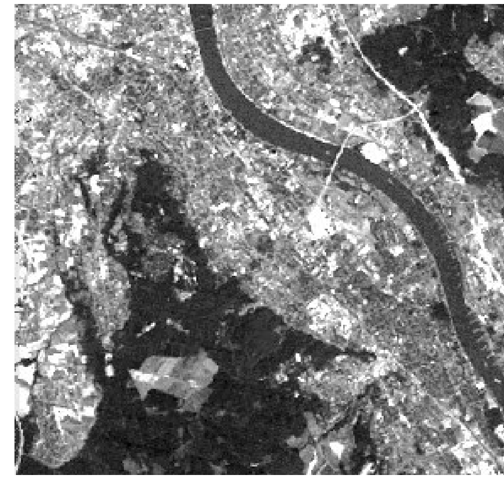
Radiometric Resolution

- **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

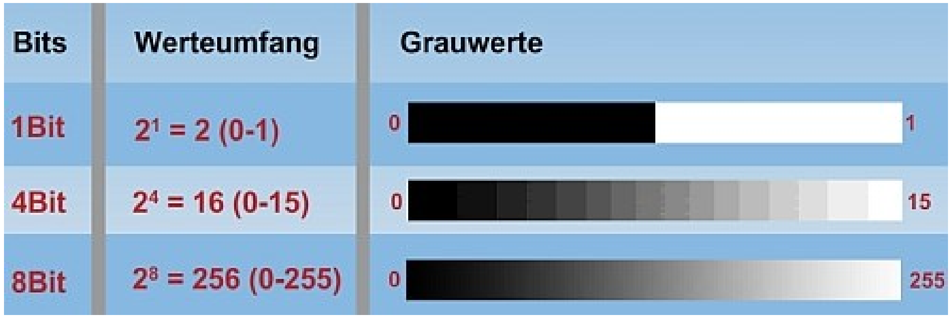
Temporal Resolution

- **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 (tasking).
  - 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?

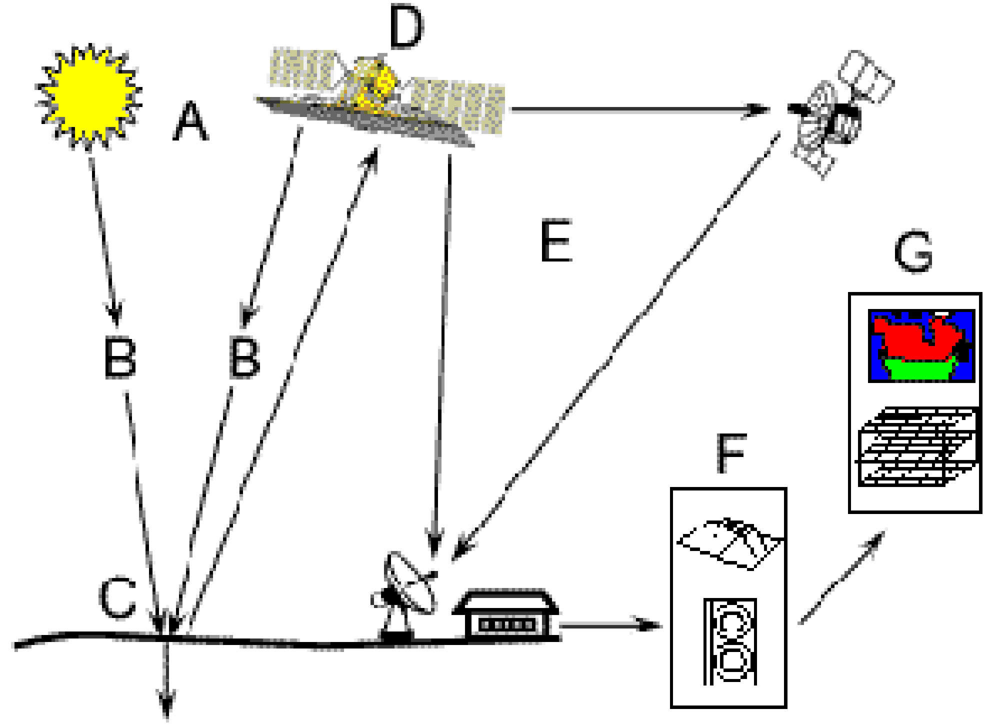
- In **<u>remote sensing</u>**, a bit stands for the number of **<u>grey-scale</u>** values a spectral sensor can tell apart (separate).
- The greater the bit number, the greater the number of grey-scale values a spectral sensor can distinguish, and therefore, the higher the radiometric resolution of a spectral sensor.
- **<u>1 bit</u>** stands for a sensor that knows only **<u>black</u>** and **<u>white</u>**.
- 2 bits equals 4 grey-scale values and (2^2)
- 4 bits equals 16 values.
  - The equation to derive the number of values is:
    - $2^{[bit]}$ = Number of grey-scale values
  - 16 bit? How many values?
    - **<u>$2^{16} = 65536$</u>**
  - What is the Max value then?



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

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)



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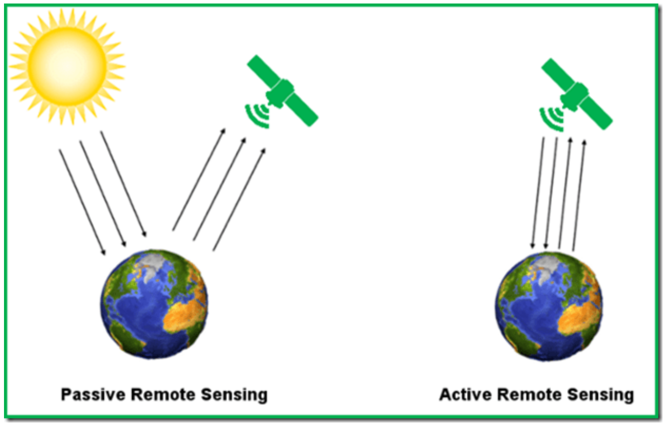
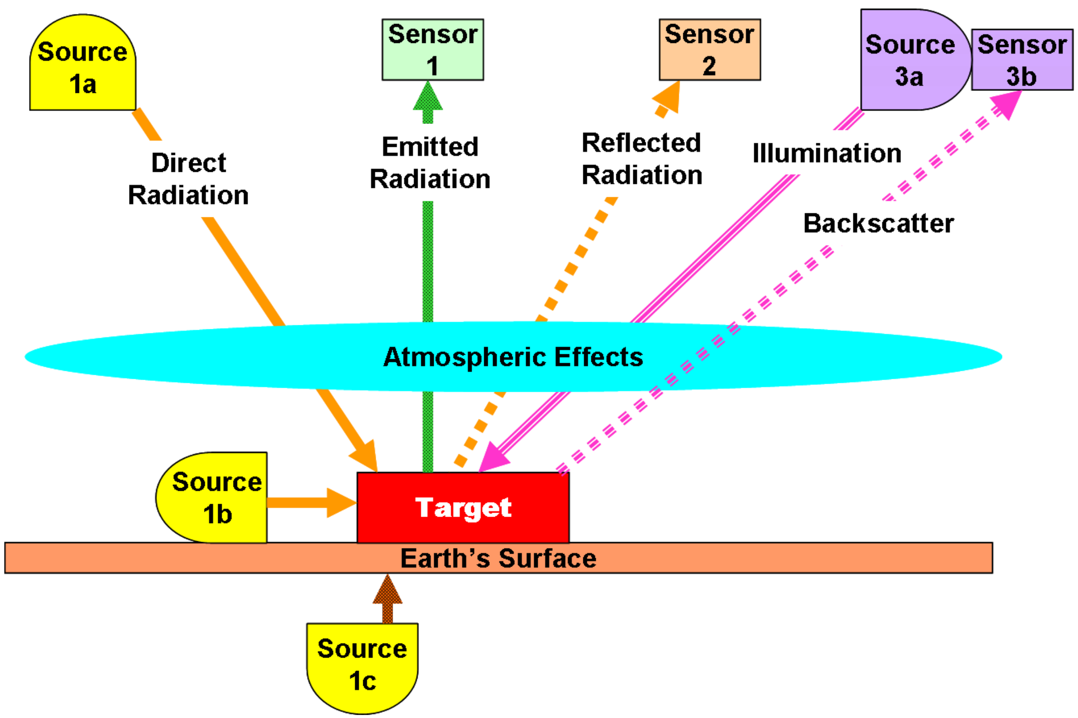
Energy Source or Illumination (A)

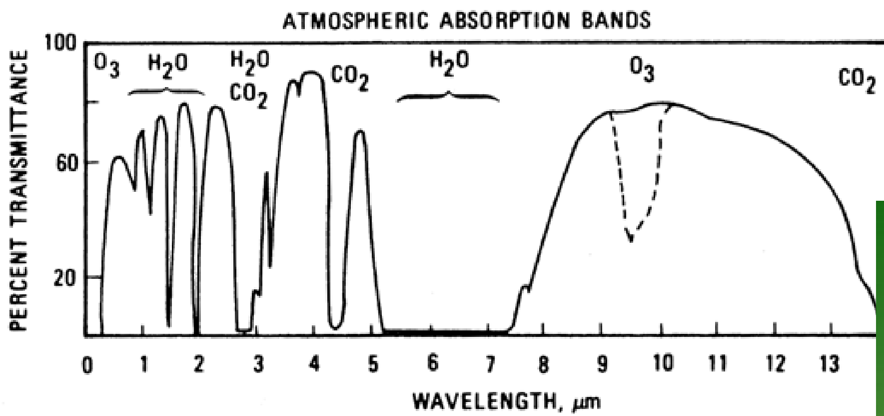
- The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
- There are two types: Active & Passive

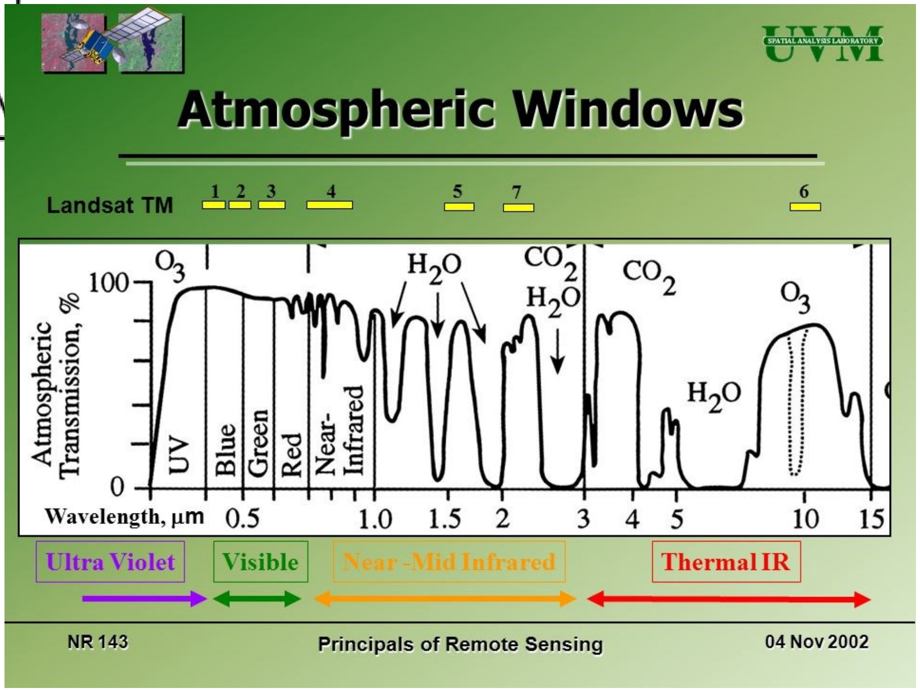




Radiation and the Atmosphere (B)

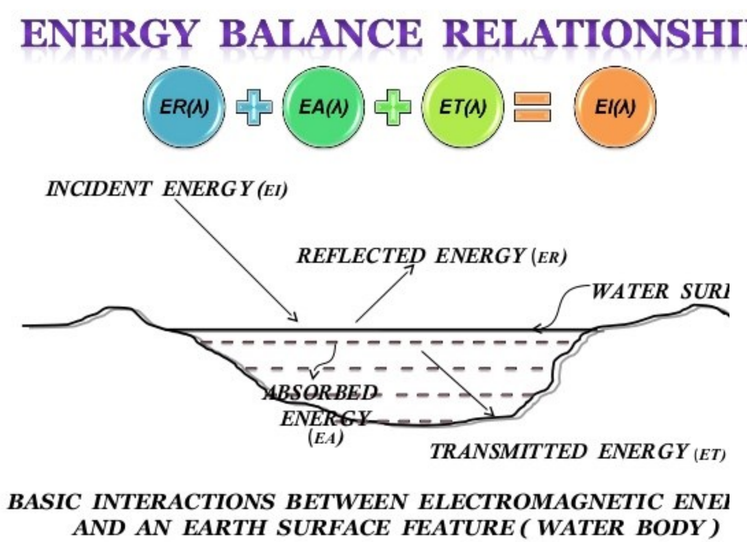
- **As** the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through.
- This interaction may take place a second time as the energy travels from the target to the sensor.

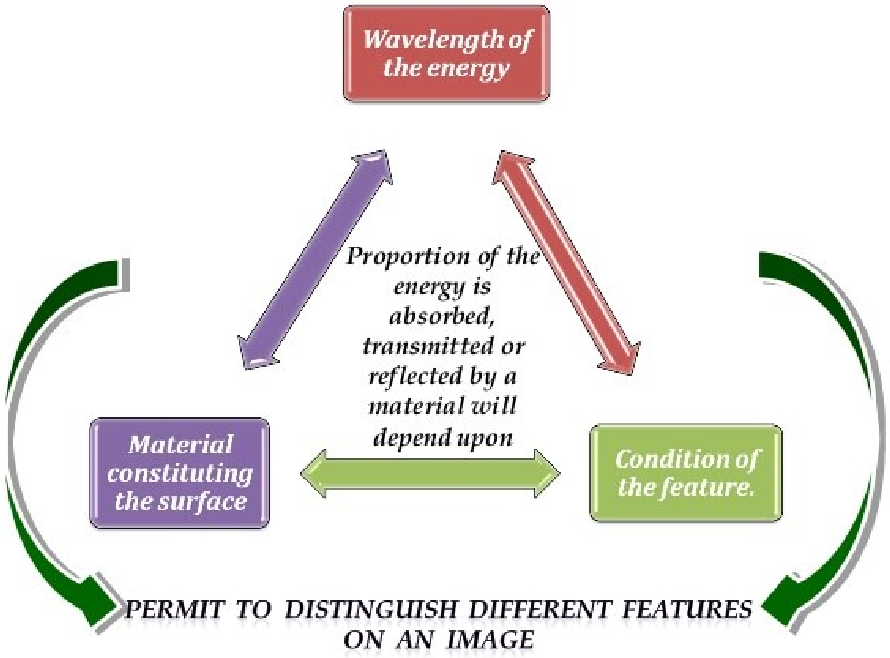




Interaction with the Target (C)

- **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

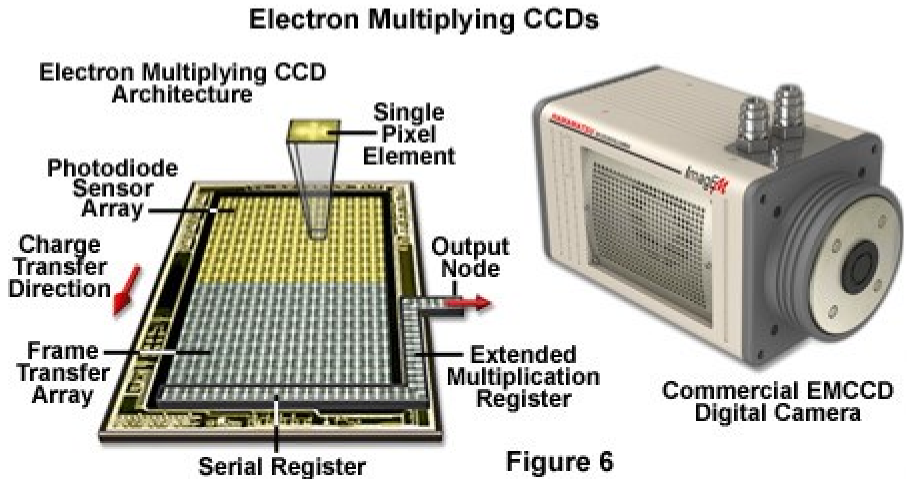
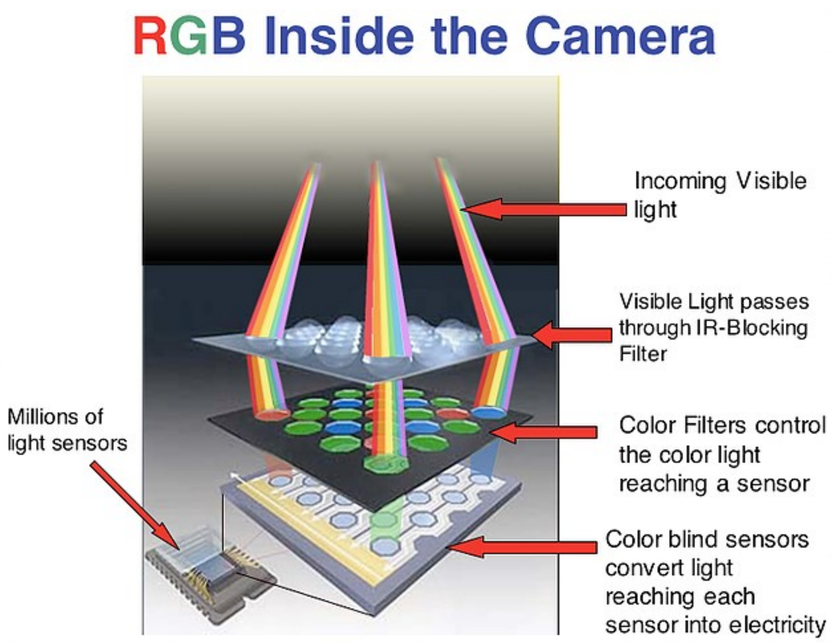


Figure 6

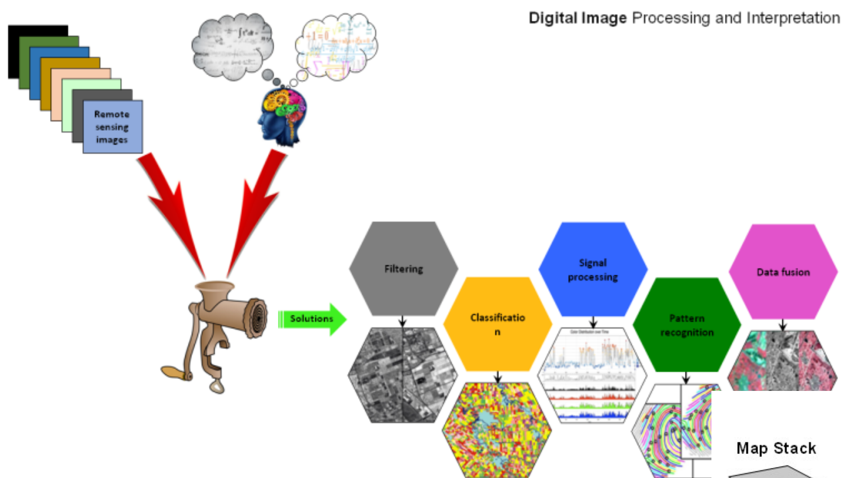


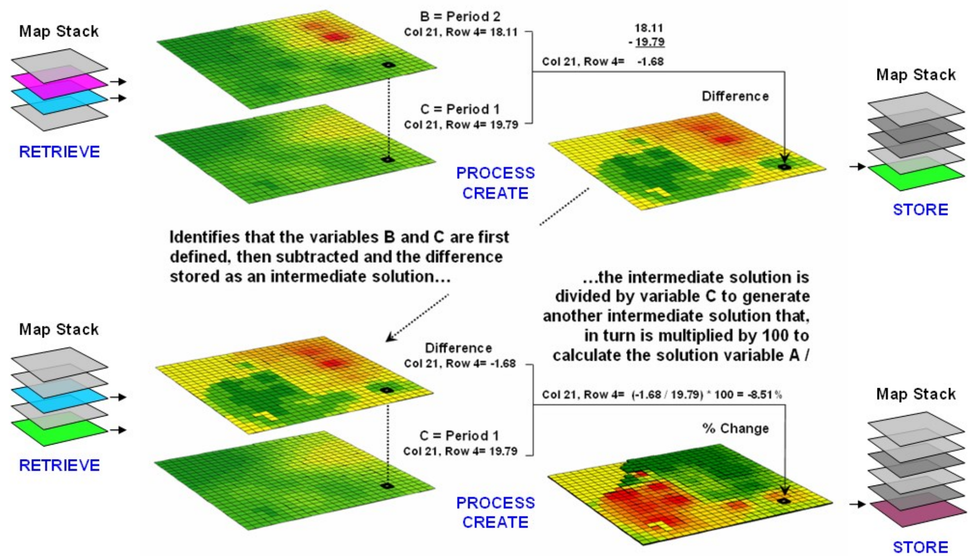
Transmission, Reception, and Processing (E)

- **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)

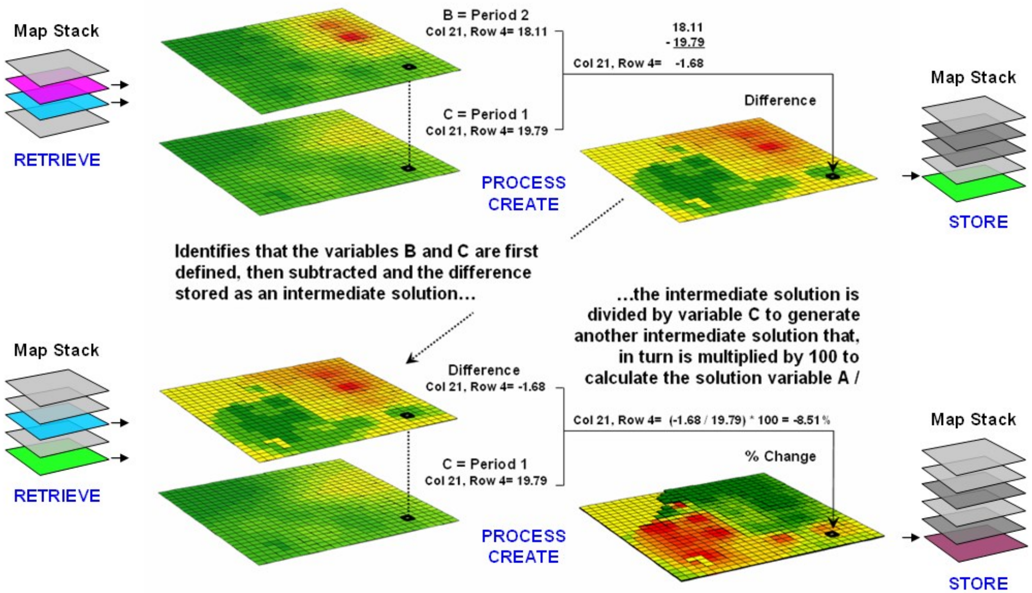
- The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.





Application (G)

- The 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 perform an internet search on the Operational Land Imager (OLI) and the MODerate resolution Imaging Spectroradiometer (MODIS) and find their 4 basic characteristics?
  - Spatial, Radiometric, Spectral, and Temporal
  - Can you find the near/most ‘recent’ AZ/Tucson image form these sensors ?

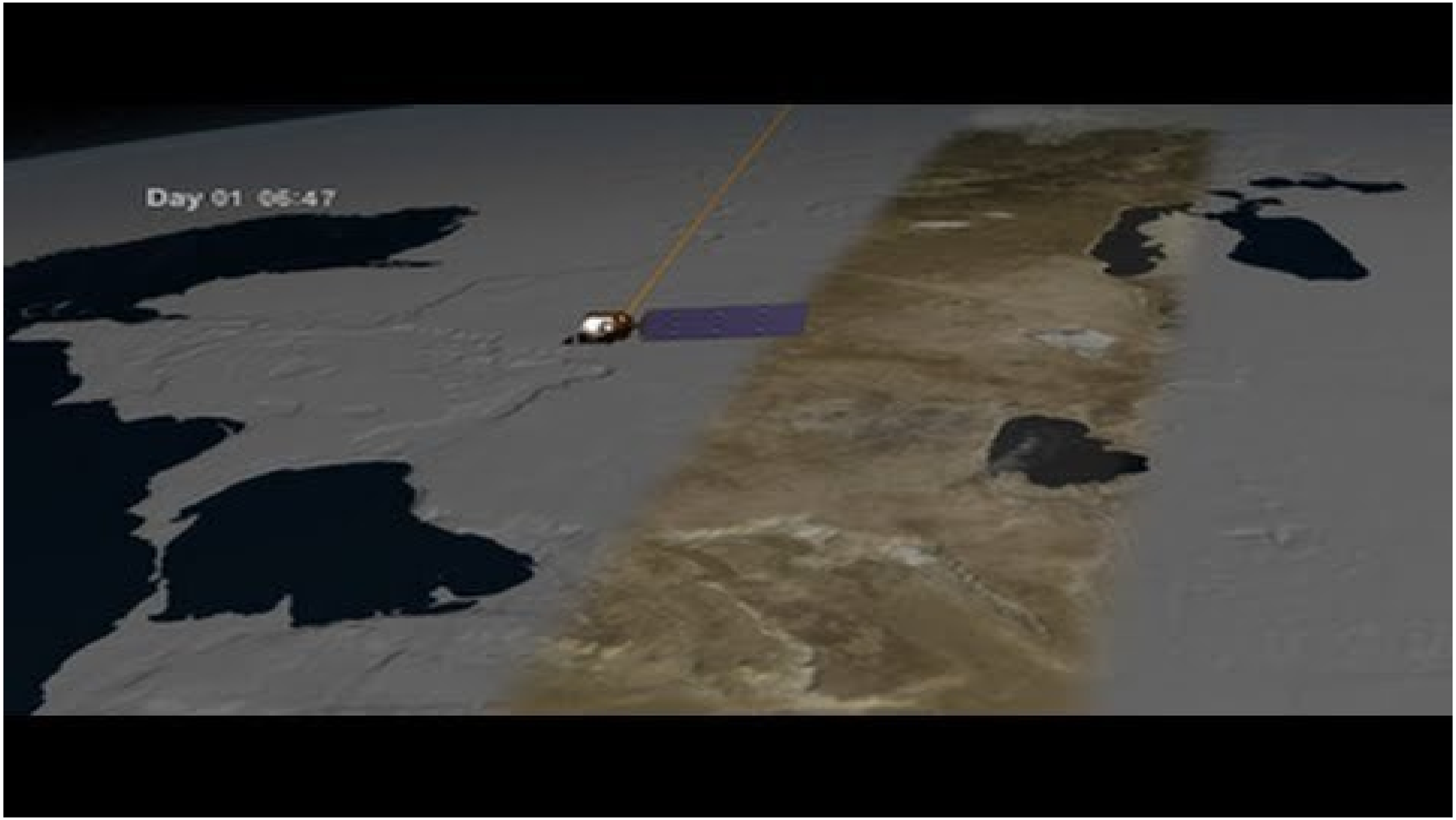
FEW PARAMETERS TO REMEMBER

Polar Orbiting Platforms – Wide Swath

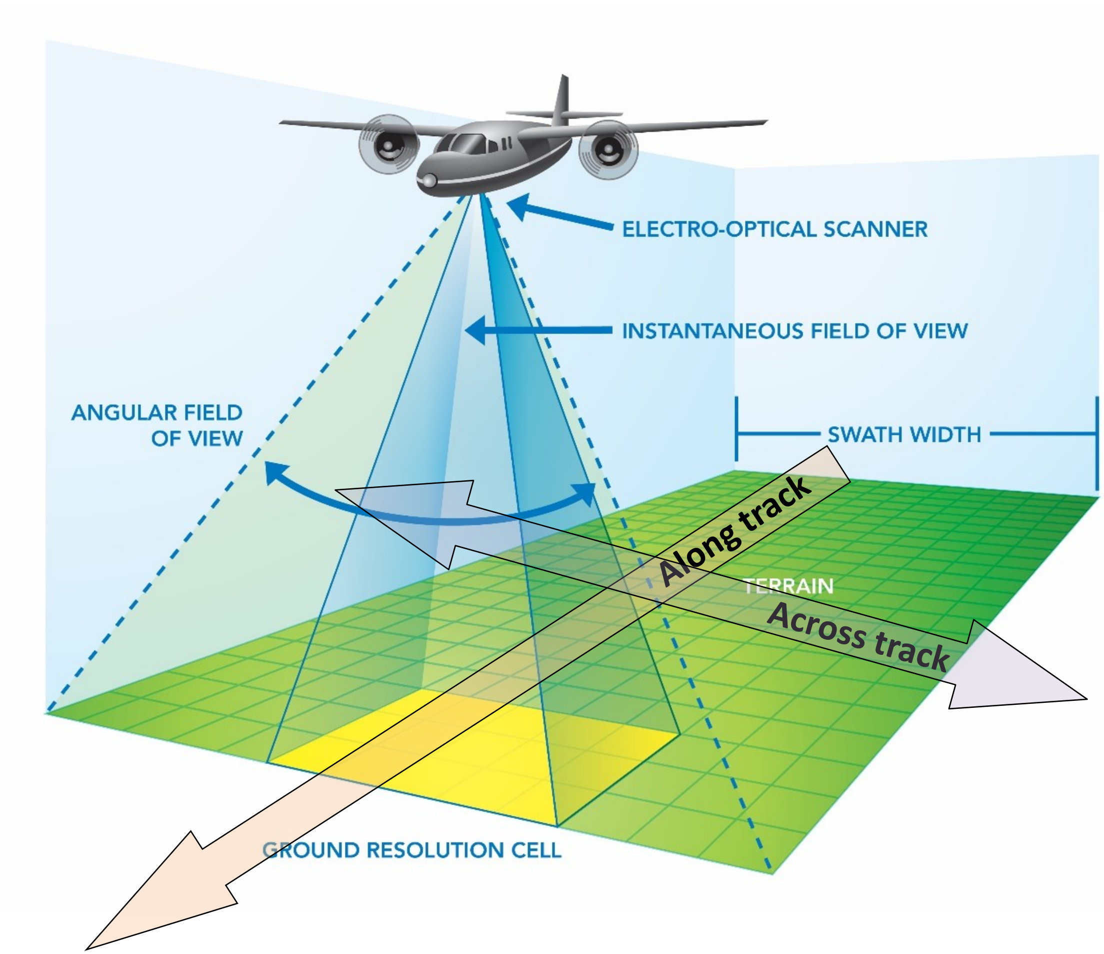
- Why wide swath?

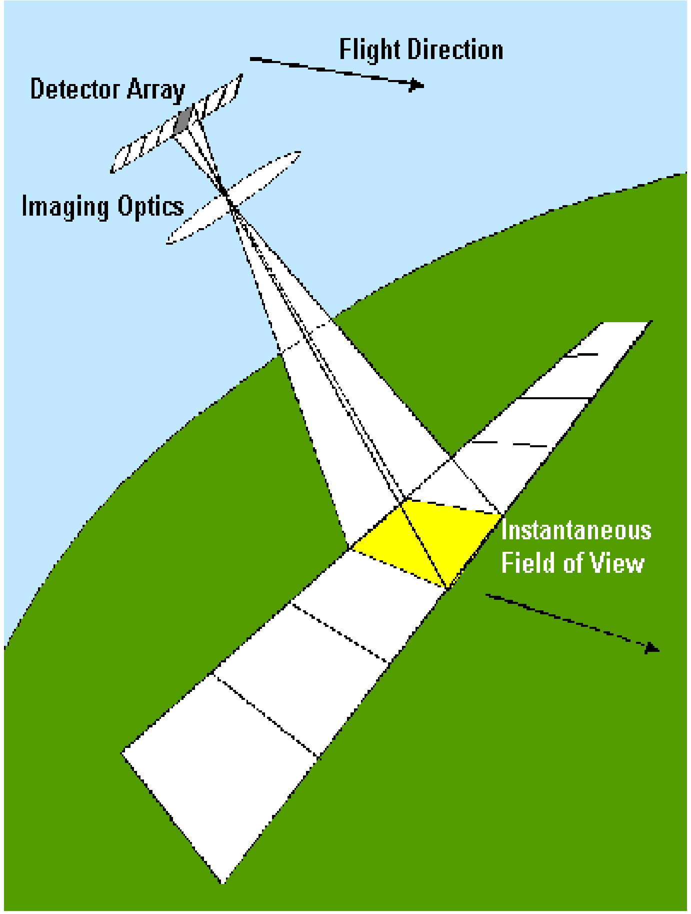
Polar Orbiting Platforms – Narrow Swath

- Why narrow swath?



Observation Arrangement

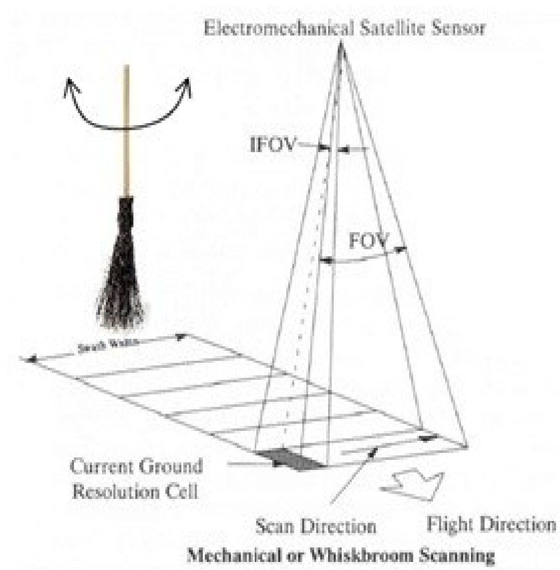




ACROSS-TRACK SCANNING

- These systems build 2-D images of the terrain beneath an aircraft.
- Uses a rotating or oscillating mirror, these scanning mirror systems scan back-and-forth along the flight line at right angles.
- Once incoming energy is reflected off the scanning mirror system, it is separated into several spectral components that are sensed independently.

Credit: NASA

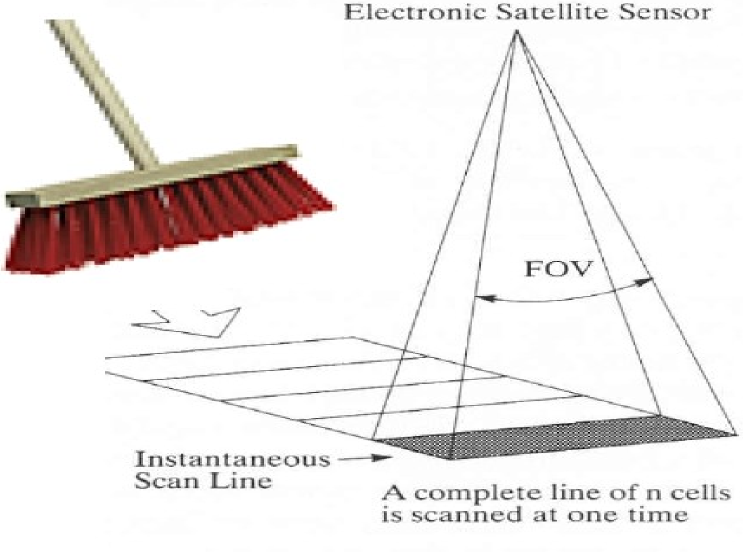


Credit: ***Fundamentals of Remote Sensing*** **- Schiewe, 2006**

ALONG-TRACK SCANNING

- Records multispectral image data beneath an aircraft, just like across-track scanners.
- Difference: linear array of detectors are used in replace of a rotating or oscillating mirror.
- Each spectral band of sensing requires its own linear array.

Credit: NASA

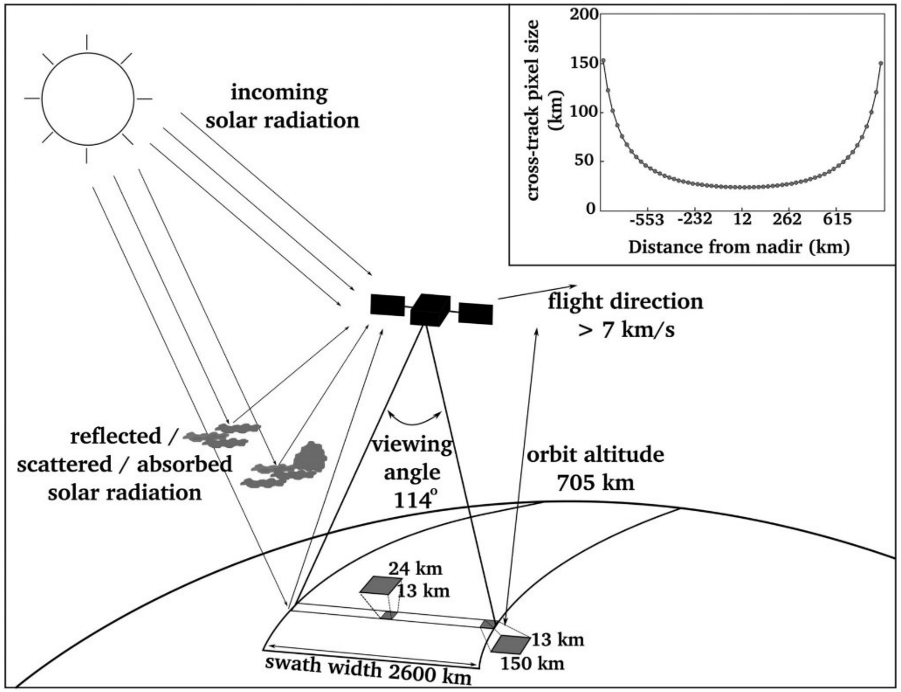


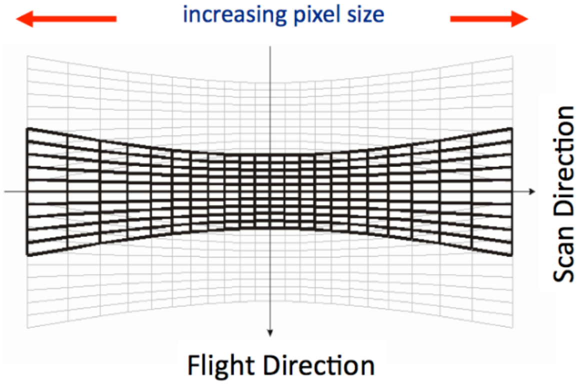
Pushbroom Concept

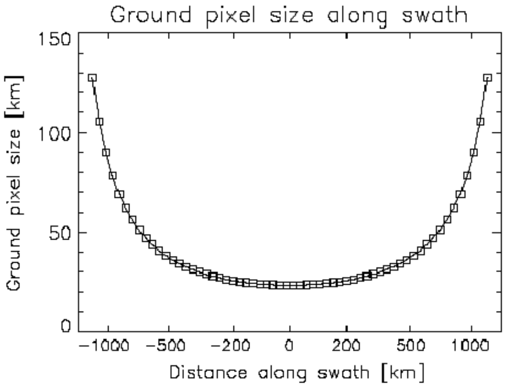
Credit: *Fundamentals of Remote Sensing* - Schiewe, 2006

Implications

- Due to Earth's curvature and the large swath size (large view angles) the observation footprint changes from nadir to swath/scan edge

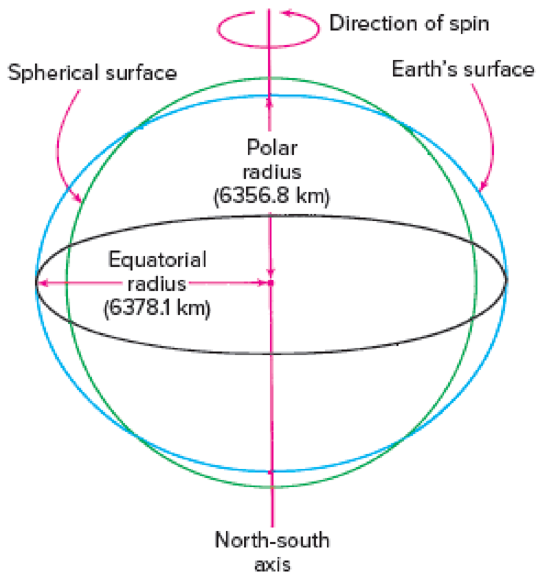


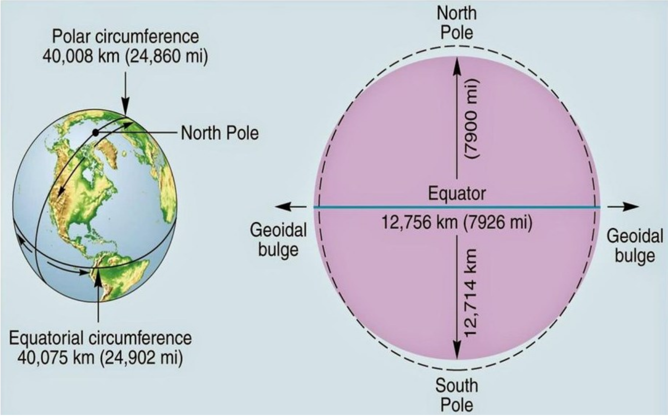




The Earth Dimensions

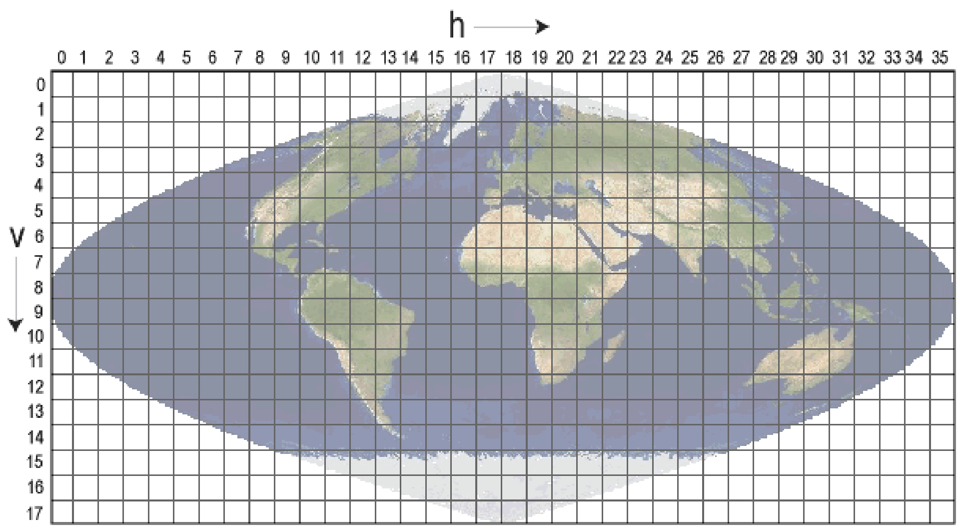
- **Radius, diameter and circumference**
  - The radius of Earth at the equator is 3,963 miles (6,378 kilometers), according to NASA's Goddard Space Flight Center.
  - However, Earth is not quite a sphere. Rotation causes it to bulge at the equator.
    - Earth's polar radius is 3,950 miles (6,356 km) — a difference of 13 miles (22 km).
- Using those measurements, the equatorial circumference of Earth is about 24,901 miles (40,075 km). However, from pole-to-pole — the meridional circumference — Earth is only 24,860 miles (40,008 km) around.
- This shape, caused by the flattening at the poles, is called an **oblate spheroid.**





So, can you now convert between degrees and m/km?

- Well, we can use the equatorial circumference which is also equal to 360 Degrees?
  - 360 Degree = 40,075 km is about ~111.3194 km/degrees
  - Or 0.008983 degree/km
- This is only true at the Equator? So keep that in mind
- MODIS (the current work horse of atmosphere, land, and Ocean remote sensing) suggests a "**40,200**" ~km circumference at the equator? (1200 km x 36)
- Use 1200 x 1 km or 4800 x 250m tiles
  - Can you compute the actual MODIS Pixels size?
  - In reality the pixel size are not exactly 1km (~926.62543305 m and ~232 m)
- Can you think or foresee another issue/challenge?
  - Elevation DEM?



Earth Rise (from the Moon)

- Series of images taken during the Apollo 8/11 missions.
- Photographer *Galen Rowell* said "*the most influential environmental photograph ever taken*"
- How relative and how insignificant Earth is

backup