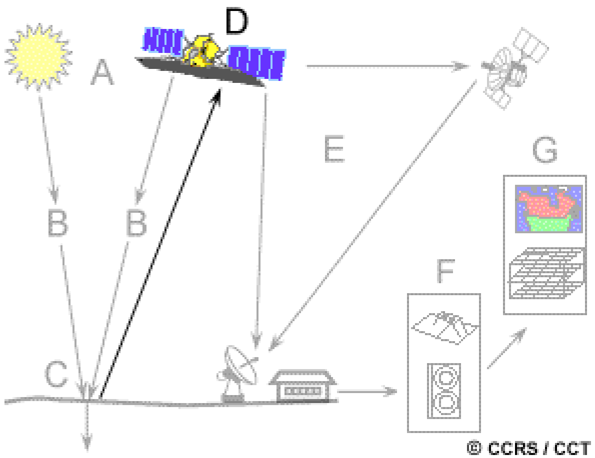
Remote Sensing

Ch. 2 Sensors (Part 1 of 3)

2.1 On the Ground, In the Air, In Space

The 4th component of the RS process :
recording of energy by the sensor (D)



Platforms for remote sensors may be situated

1. on the **ground**,
2. on an **aircraft** or *balloon*,
3. on a **satellite** or *spacecraft* outside of the Earth's atmosphere.

Ground-based sensors

- used to record **detailed information** about the surface which is compared with information collected from aircraft or satellite sensors.
- used to **better characterize the target** which is being imaged by other sensors, making it possible to **better understand** the information in the imagery.
- Sensors may be placed on a **ladder**, **scaffolding**, **tall building, cherry-picker, crane**, etc.

2.1 On the Ground, In the Air, In Space

Aerial platforms

- are primarily stable wing **aircraft**.
- often used to collect **very detailed images** and facilitate the collection of data over virtually **any portion** of the Earth's surface at **any time**.

Satellite platforms

- In space, remote sensing is sometimes conducted from the **space shuttle** or, more commonly, from **satellites**.
- **Satellites** are objects which revolve around the Earth. Because of their orbits, satellites permit **repetitive coverage** of the Earth's surface on a continuing basis.

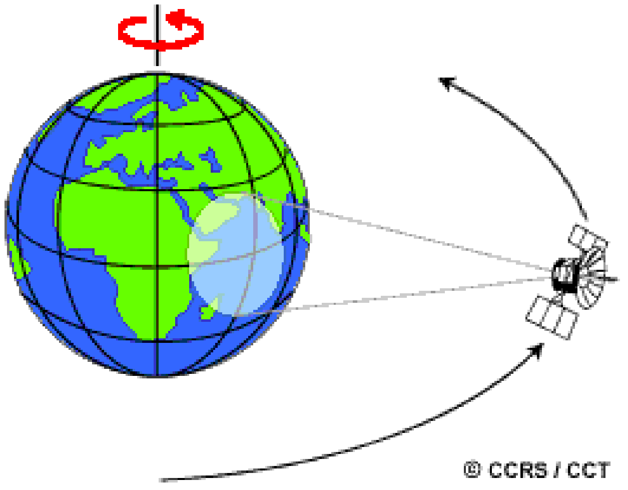
2.2 Satellite Characteristics: Orbits and Swaths

Satellites have several unique characteristics which make them particularly useful for remote sensing of the Earth's surface.

Orbit : The **path followed** by a satellite. Satellite orbits are matched to the **capability** and **objective** of the sensor(s) they carry. Orbit selection can vary in terms of altitude and their orientation and rotation relative to the Earth.

Geostationary orbits

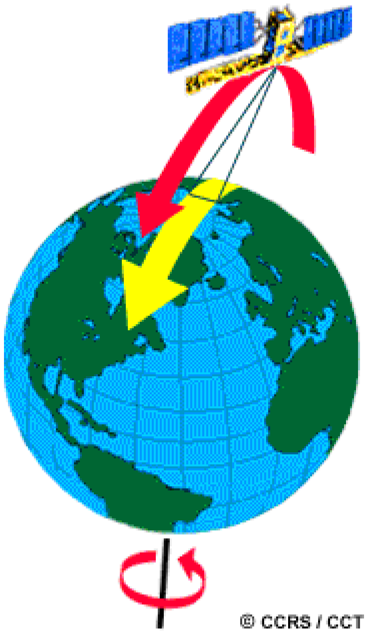
- very high altitudes (~ 36,000 Km), which **view the same portion of the Earth's surface at all times.**
- **revolve at speeds** which match the rotation **of the Earth** so they seem **stationary**, relative to the Earth's surface. This allows the satellites to **observe and collect information continuously** over specific areas.
- **Weather & communications** satellites
- Due to their **high altitude**, some geostationary weather satellites can **monitor weather and cloud patterns covering an entire hemisphere** of the Earth.



2.2 Satellite Characteristics: Orbits and Swaths

Near-polar orbits

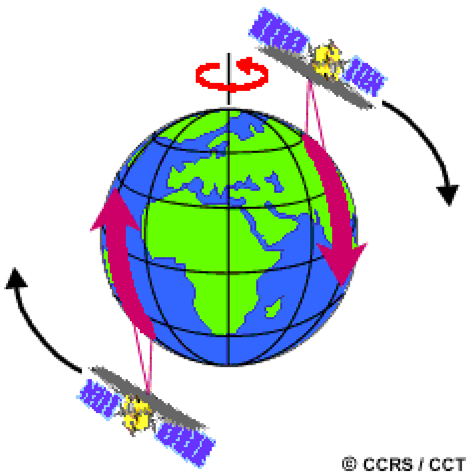
- A **north-south orbit** which, in conjunction with the Earth's rotation (west-east), allows **to cover most of the Earth's surface** over a certain period of time. These are **near-polar orbits**, so named for the inclination of the orbit relative to a line running between the North and South poles.



- **sun-synchronous**
  - they cover each area of the world at a constant local time of day (**local sun time)**. At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season.
  - It ensures **consistent illumination conditions** when acquiring images in a specific season over successive years, or over a particular area over a series of days.
  - This is an important factor for **monitoring changes** between images or for **mosaicking adjacent images** together, as they do not have to be corrected for different illumination conditions.

2.2 Satellite Characteristics: Orbits and Swaths

- Most of the remote sensing satellite platforms today are in near-polar orbits, which means that the satellite **travels northwards** on one side of the Earth and then **toward the southern pole** on the second half of its orbit. These are called **ascending & descending passes**, respectively.



- If the orbit is also sun-synchronous, the **ascending pass** is most likely **on the shadowed side** of the Earth while the **descending pass is on the sunlit side.**

- Sensors **recording reflected** solar energy only image the surface on a **descending pass**, when solar illumination is available.

- **Active sensors** which provide their own illumination or **passive sensors** that record emitted (e.g. thermal) radiation can also image the surface on **ascending passes**.

2.2 Satellite Characteristics: Orbits and Swaths

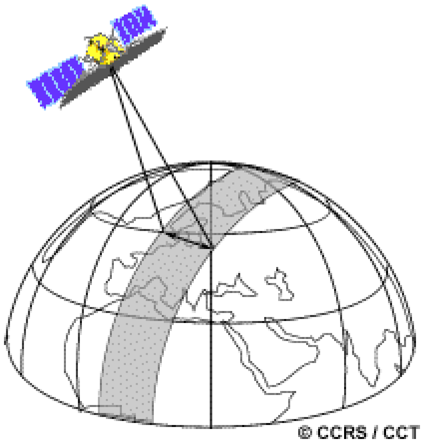
- **Swath** : The **area imaged** on the Earth's surface by the sensors when a satellite revolves around the Earth.

- Imaging **swaths for spaceborne sensors** generally vary between **tens** and **hundreds of Km wide**.

- As the satellite orbits the Earth from pole to pole, it seems that the satellite is shifting westward because the **Earth is rotating** (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each consecutive pass.

- The **satellite's orbit** and the **rotation of the Earth** work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.

- **Orbit cycle :** completed when the satellite retraces its path, passing over the same point on the Earth's surface directly below the satellite (called the **nadir** point) for a second time.



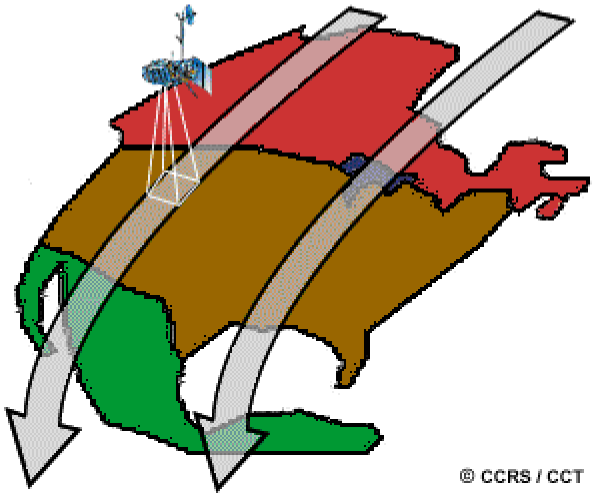
2.2 Satellite Characteristics: Orbits and Swaths

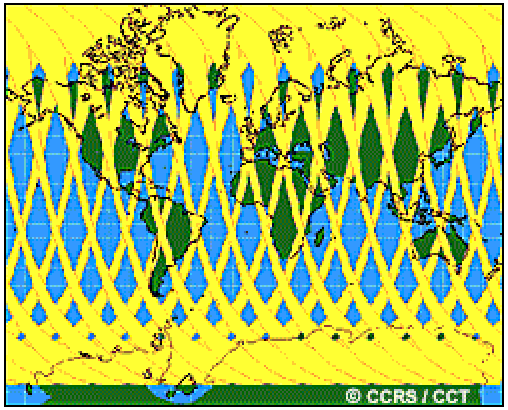
- **revisit period** is **not** the same as the time for its **orbit cycle**

- Using **steerable sensors**, an satellite-borne instrument can view an area (off-nadir) before and after the orbit passes over a target, thus making the **'revisit' time less than the orbit cycle time**.

- **Revisit period** is an important consideration for a number of monitoring applications, especially when frequent imaging is required (e.g. to monitor the spread of an oil spill, or the extent of flooding).

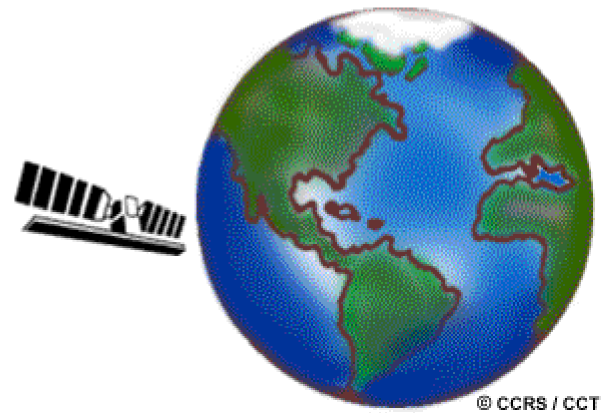
- In near-polar orbits, areas at **high latitudes** will be **imaged more frequently** than the equatorial zone due to the **increasing overlap in adjacent swaths** as the orbit paths come closer together near the poles.





2.2 Satellite Characteristics: Orbits and Swaths

Did You Know?



- **…** most of the images you see on television **weather forecasts** are from **geostationary satellites**. This is because they provide broad coverage of the weather and cloud patterns on continental scales. Meteorologists (weather forecasters) use these images to determine in which direction the weather patterns are likely to go. The **high repeat coverage capability** of satellites with geostationary orbits allows them to **collect several images daily** to allow these patterns to be closely monitored.

- … satellites occasionally require their orbits to be corrected. Because of **atmospheric drag** and other forces that occur when a satellite is in orbit, they may **deviate from their initial orbital path**. In order to maintain the planned orbit, a control center on the ground will issue commands to the satellite to place it back in the proper orbit. Most satellites and their sensors have **a finite life-span** ranging **from a few to several years**. Either the sensor will cease to function adequately or the satellite will suffer severe orbit decay such that the system is no longer useable.

2.2 Satellite Characteristics: Orbits and Swaths

Quiz 1 What **advantages** do sensors carried on board **satellites** have over those carried on **aircraft**? Are there any **disadvantages** that you can think of?

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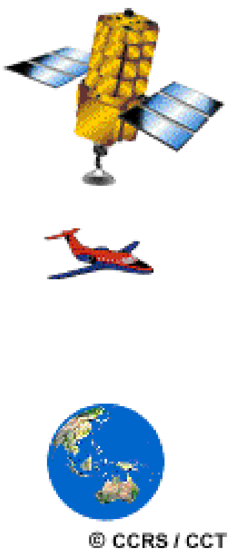

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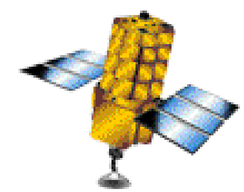

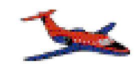

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Advantages (1) Sensors on satellites **can "see" a much larger area** of the Earth's surface than would be possible from a sensor onboard an aircraft. **(2)** Because they are continually orbiting the Earth, it is relatively easy to collect imagery **on a systematic and repetitive basis** in order to monitor changes over time. **(3)** The **geometry** of orbiting satellites with respect to the Earth can be calculated quite **accurately** and facilitates correction of images to their proper geographic orientation and position.

Disadvantage : **(1)** aircraft sensors can collect data at **any time** and over **any portion** of the Earth's surface while satellite sensors are restricted to collecting data over only those areas and during specific times dictated by their orbits.

(2) It is much more **difficult to fix a sensor in space** if a problem or malfunction develops.

2.2 Satellite Characteristics: Orbits and Swaths

Quiz 2 As a satellite in a near-polar sun-synchronous orbit revolves around the Earth, the satellite crosses the equator at approximately the same local sun time every day. Because of the orbital velocity, all other points on the globe are passed either slightly before or after this time. For a sensor in the visible portion of the spectrum, what would be the **advantages** and **disadvantages** of **crossing times** (local sun time) **a)** in the early morning, **b)** around noon, and **c)** in the mid afternoon?

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Quiz 2 As a satellite in a near-polar sun-synchronous orbit revolves around the Earth, the satellite crosses the equator at approximately the same local sun time every day. Because of the orbital velocity, all other points on the globe are passed either slightly before or after this time. For a sensor in the visible portion of the spectrum, what would be the **advantages** and **disadvantages** of crossing times (local sun time) **a)** in the early morning, **b)** around noon, and **c)** in the mid afternoon?

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(a) early morning : • the sun at a very low angle in the sky
• good for emphasizing topographic effects but would result in a lot of shadow in areas of high relief.

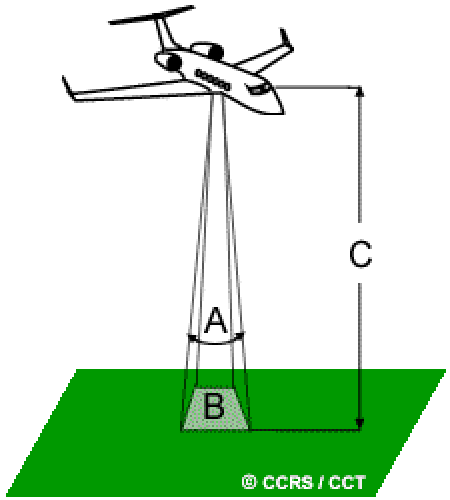
(b) around noon : • the sun at its highest point in the sky and provide the maximum and most uniform illumination conditions
• useful for surfaces of low reflectance but might cause saturation of the sensor over high reflectance surfaces, such as ice.

(c) the mid afternoon : • the illumination conditions would be more moderate
• solar heating causes difficulties for recording reflected energy.

In order to minimize between these effects, most satellites which image in the visible, reflected, and emitted infrared regions use crossing times **around mid-morning** as a compromise.

2.3 Spatial Resolution, Pixel Size, and Scale

Spatial resolution



- **the size** of the **smallest** possible feature that can be **detected**.
- depends primarily on their **Instantaneous Field of View (IFOV)**. The **IFOV** is **the angular cone of visibility of the sensor (A).**
- The **IFOV** determines **the area (B)** on the Earth's surface which is "seen" from a given **altitude (C)** at one particular moment in time. **The size of the area** viewed is determined by **multiplying** the **IFOV** by the **distance** from the ground to the sensor (C).
- This area on the ground **(B)** is called the **resolution cell** and determines a **sensor's maximum spatial resolution**.

- For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If the feature is smaller than this, it may not be detectable as the average brightness of all features in that resolution cell will be recorded. However, smaller features may sometimes be detectable if their reflectance dominates within a particular resolution cell allowing sub-pixel or resolution cell detection.

2.3 Spatial Resolution, Pixel Size, and Scale

- **Pixel size** : Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel size and spatial resolution - they are not interchangeable.

- If a sensor has a spatial resolution of 20 meters and an image from that sensor is displayed **at full resolution**, each pixel represents an area of 20m x 20m on the ground. In this case the **pixel size and resolution are the same**. However, it is possible to display an image with a pixel size different than the resolution. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same.

2.3 Spatial Resolution, Pixel Size, and Scale

- In **coarse** or **low resolution** images, only large features are visible are said to have**.** In **fine or high resolution** images, small objects can be detected. Generally speaking, <u>the finer the resolution, the less total ground area</u> can be seen.

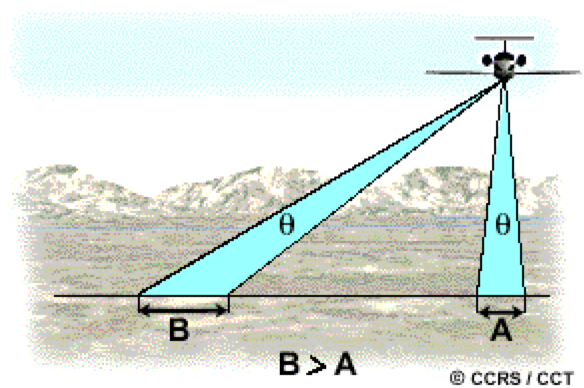
- **Military sensors** are designed to view as much detail as possible, and therefore have **very fine resolution**. **Commercial satellites** provide imagery with resolutions varying **from a few meters to several Km**.

- **Scale** : **The ratio of distance** on an image or map, **to actual ground distance** is referred to as scale. If you had a map with a scale of 1:100,000, 1cm length on the map = 100,000cm (1km) long on the ground. Maps or images with small "map-to-ground ratios" are referred to as **small scale** (e.g. 1:100,000), and those with larger ratios (e.g. 1:5,000) are called **large scale**.

2.3 Spatial Resolution, Pixel Size, and Scale

Did you know?

If the IFOV for all pixels of a scanner stays constant (which is often the case), then the ground area represented by pixels at the nadir will have a larger scale then those pixels which are off-nadir. This means that **spatial resolution** will **vary from the image centre to the swath edge.**



2.3 Spatial Resolution, Pixel Size, and Scale

Quiz 1 Look at the detail apparent in each of these two images. Which of the two images is of a smaller scale? What clues did you use to determine this? Would the imaging platform for the smaller scale image most likely have been a satellite or an aircraft?

ANS

2.3 Spatial Resolution, Pixel Size, and Scale

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ANS

- The image on **the top is from a satellite** while the image on **the bottom is from an aircraft**.
- We are able to identify relatively small features (i.e. individual buildings) in the image on the bottom that are not discernible in the image on the top. Only general features such as street patterns, waterways, and bridges can be identified in the top image.
- Because features appear larger in the image on the **bottom** and a particular measurement (eg. 1 cm) on the image represents a smaller true distance on the ground, this image is at a **larger scale**.

2.3 Spatial Resolution, Pixel Size, and Scale

Quiz 2 If you wanted to monitor the general health of all vegetation cover over the Canadian Prairie provinces for several months, what type of platform and sensor characteristics (spatial, spectral, and temporal resolution) would be best for this and why?

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2.3 Spatial Resolution, Pixel Size, and Scale

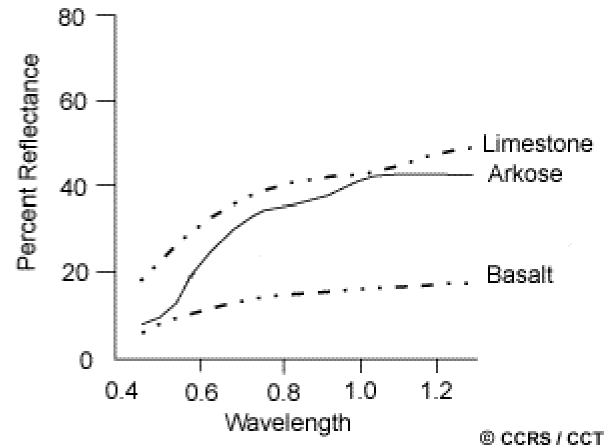
Quiz 2 If you wanted to monitor the general health of all vegetation cover over the Canadian Prairie provinces for several months, what type of platform and sensor characteristics (spatial, spectral, and temporal resolution) would be best for this and why?

ANS

- **fairly coarse spatial resolution :** The large east-to-west expanse would be best covered by a sensor with a wide swath and broad coverage. This would also imply that the spatial resolution of the sensor would be fairly coarse.
- **high temporal resolution** : With broad areal coverage the revisit period would be shorter, increasing the opportunity for repeat coverage necessary for monitoring change. The frequent coverage would also allow for areas covered by clouds on one date, to be filled in by data collected from another date, reasonably close in time.
- **low spectral resolution** : The sensor would not necessarily require high spectral resolution, but would at a minimum, require channels in the visible and near-infrared regions of the spectrum. Vegetation generally has a low reflectance in the visible and a high reflectance in the near-infrared. The contrast in reflectance between these two regions assists in identifying vegetation cover. The magnitude of the reflected infrared energy is also an indication of vegetation health.
- A sensor on board the U.S. **NOAA** series of satellites with exactly these types of characteristics is actually used for this type of monitoring over the entire surface of the Earth!

2.4 Spectral Resolution

- **Spectral response** and **spectral emissivity curves** characterize the reflectance and/or emittance of a feature or target over a variety of wavelengths. Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges.



- **Broad classes**, such as **water and vegetation**, can usually be separated using very broad wavelength ranges - the visible and near infrared.

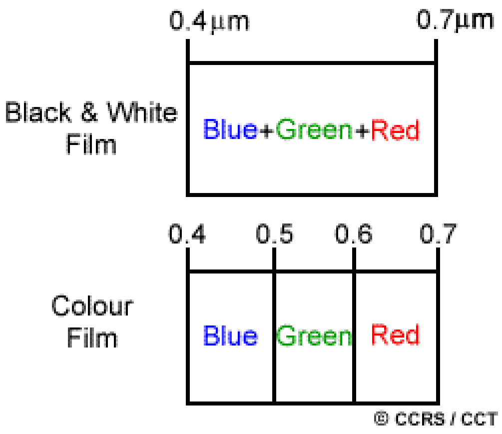
- **Specific classes**, such as **different rock types**, may not be easily distinguishable using either of these broad wavelength ranges and would require comparison at much finer wavelength ranges to separate them. Thus, we would require a sensor with **higher spectral resolution**.

- **Spectral resolution** describes **the ability of a sensor to define fine wavelength intervals**. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

2.4 Spectral Resolution

- **Black and white film** records wavelengths extending all of the visible portion of the EM spectrum. Its **spectral resolution** is fairly **coarse**, as the various wavelengths of the visible spectrum are not individually distinguished and the overall reflectance in the entire visible portion is recorded.

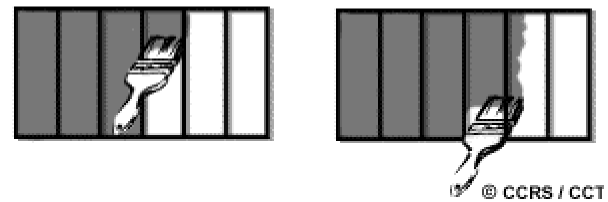
- **Color film** is also sensitive to the reflected energy over the visible portion of the spectrum, but has **higher spectral resolution**, as it is individually sensitive to the reflected energy at the blue, green, and red wavelengths of the spectrum. Thus, it can represent features of various colors based on their reflectance in each of these distinct wavelength ranges.



- **Multi-spectral sensors** : remote sensing systems which record energy over several separate wavelength ranges at various spectral resolutions. Advanced multi-spectral sensors called **hyperspectral** sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the EM spectrum.

2.4 Spectral Resolution

Quiz 1 Hyperspectral scanners are special multispectral sensors which detect and record radiation in several (perhaps hundreds) of very narrow spectral bands. What would be some of the advantages of these types of sensors? What would be some of the disadvantages?



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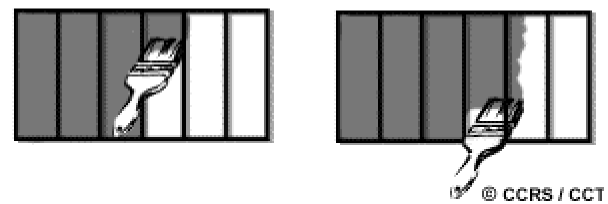


ANS Hyperspectral scanners have **very high spectral resolution** because of their narrow bandwidths. By measuring radiation over several small wavelength ranges, we are able to effectively build up a continuous spectrum of the radiation detected for each pixel in an image. This allows for **fine differentiation** between targets based on detailed reflectance and absorption responses which are not detectable using the broad wavelength ranges of conventional multispectral scanners.

However, with this increased sensitivity comes **significant increases in the volume** of data collected. This makes both **storage** and **manipulation** of the data much more difficult. **Analyzing** multiple images at one time or combining them, becomes cumbersome, and trying to identify and explain what each unique response represents in the "real world" is often difficult.

2.4 Spectral Resolution

Quiz 2 If the spectral range of the 288 channels of the CASI (Compact Airborne Spectrographic Imager) is exactly 0.4 μm to 0.9 μm and each band covers a wavelength of 1.8 nm (nanometres, 10^{-9} m), will there be any overlap between the bands?

ANS

2.4 Spectral Resolution

Quiz 2 If the spectral range of the 288 channels of the CASI (Compact Airborne Spectrographic Imager) is exactly 0.4 μm to 0.9 μm and each band covers a wavelength of 1.8 nm (nanometres, 10^{-9} m), will there be any overlap between the bands?

ANS The total wavelength range available will be 0.9-0.4 μm = 0.5 μm. If there are 288 channels of 1.8 nm each, let's calculate the total wavelength range they would span if they did not overlap.

1.8 nm = 1.8 x 10^{-9} m

1.8 x10^{-9} m X 288 = 0.0000005184 m

0.0000005184 m = 0.5184 μm

Since 0.5184 is greater than 0.5, the answer is YES, there will be have to be some overlap between some or all of the 288 bands to fit into this 0.5 μm range.

2.5 Radiometric Resolution

radiometric resolution

- ability to discriminate very slight differences in energy.

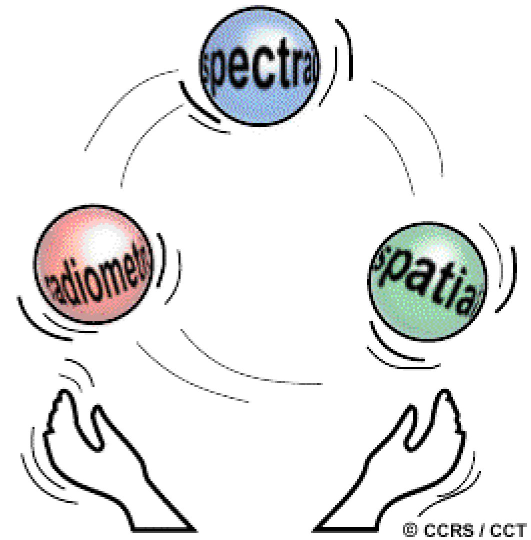
- determined by its **sensitivity to the magnitude of the EM energy** when an image is acquired on film or by a sensor.

- **The finer the radiometric resolution** of a sensor, **the more sensitive** it is to detecting small differences in reflected or emitted energy.

- In imagery data, the maximum number of brightness levels available depends on the number of bits used. Thus, if a sensor used 8 bits to record the data, $2^8=256$ digital values (0~255) available. However, if only 4 bits were used, only $2^4=16$ values (0~15) would be available. Thus, the radiometric resolution would be much less. Image data are generally displayed in a range of grey tones, with black representing 0 and white representing the maximum value (for example, 255 in 8-bit data). By **comparing a 2-bit image with an 8-bit image**, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions.

2.5 Radiometric Resolution

Did you Know?



…that there are **trade-offs between spatial, spectral, and radiometric resolution** which must be taken into consideration when engineers design a sensor.

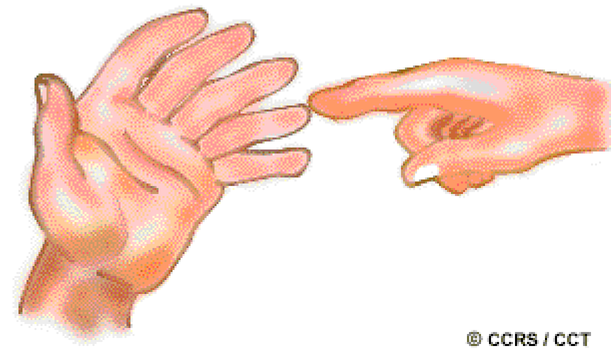
- For **high spatial resolution**, the sensor has to have a small IFOV (Instantaneous Field of View). However, this reduces the amount of energy that can be detected as the area of the ground resolution cell within the IFOV becomes smaller. This leads to **reduced radiometric resolution** - the ability to detect fine energy differences.

- To **increase the radiometric resolution** without reducing spatial resolution, we would have to broaden the wavelength range detected for a particular channel or band. Unfortunately, this would **reduce the spectral resolution** of the sensor.

- Conversely, **coarser spatial resolution** would allow **improved radiometric and/or spectral resolution**. Thus, these three types of resolution must be balanced against the desired capabilities and objectives of the sensor.

2.5 Radiometric Resolution

Quiz Suppose you have a digital image which has a radiometric resolution of 6 bits. What is the maximum value of the digital number which could be represented in that image?



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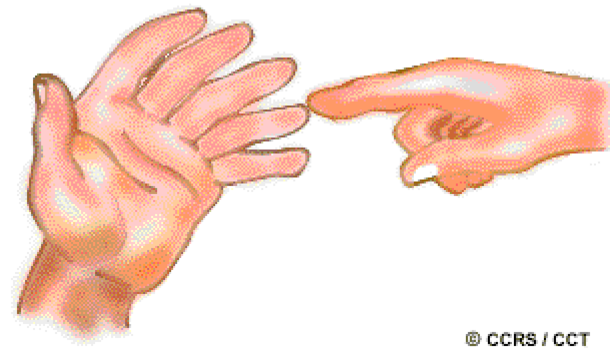
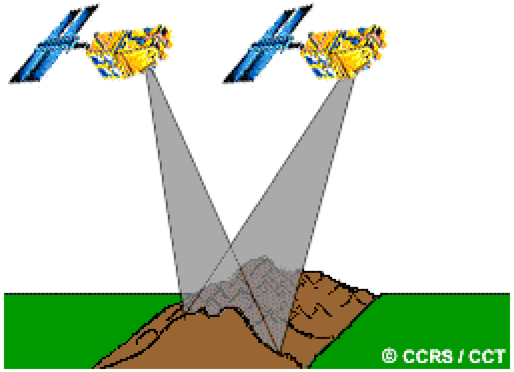


ANS The number of digital values possible in an image is equal to the number two raised to the exponent of the number of bits in the image (i.e. $2^{\#\text{ of bits}}$). The number of values in a 6-bit image would be equal to $2^6 = 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$. Since the range of values displayed in a digital image normally starts at zero (0), in order to have 64 values, the maximum value possible would be 63.

2.6 Temporal Resolution

temporal resolution



- **the absolute temporal resolution** is equal to the **revisit period** (the length of time it takes for a satellite to complete one entire orbit cycle or to image the exact same area at the same viewing angle a second time). The revisit period of a satellite sensor is **usually several days**.

- However, because of some degree of overlap in the imaging **swaths** of adjacent orbits for most satellites and the increase in this overlap with increasing **latitude**, some areas of the Earth tend to be re-imaged more frequently. Also, some satellite systems are able to **point their sensors to image the same area** between different satellite passes separated by periods from one to five days.

- Thus, **the actual temporal resolution** of a sensor depends on a variety of factors, including the **satellite/sensor capabilities**, the **swath overlap**, and **latitude**.

2.6 Temporal Resolution

- Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing **multi-temporal imagery**. The multi-temporal imaging is one of the most important elements for applying remote sensing data.

- **Ex)** During the growing season, most species of vegetation are in a continual state of change and our ability to monitor those subtle changes using remote sensing is dependent on when and how frequently we collect imagery. By imaging on a continuing basis at different times we are able to monitor the changes that take place on the Earth's surface, whether they are naturally occurring (such as changes in natural vegetation cover or flooding) or induced by humans (such as urban development or deforestation).

- The time factor in imaging is important when
  - persistent clouds offer limited clear views of the Earth's surface (often in the tropics)
  - short-lived phenomena (floods, oil slicks, etc.) need to be imaged
  - multi-temporal comparisons are required (e.g. the spread of a forest disease from one year to the next)
  - the changing appearance of a feature over time can be used to distinguish it from near-similar features (wheat / maize)