IMAGE DATA ANALYSIS (6CFU)

MODULE OF

REMOTE SENSING

(9 CFU)

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MASTER OF SCIENCE IN COMMUNICATION TECHNOLOGIES AND MULTIMEDIA
MASTER OF SCIENCE IN COMPUTER SCIENCE, LM INGEGNERIA INFORMATICA

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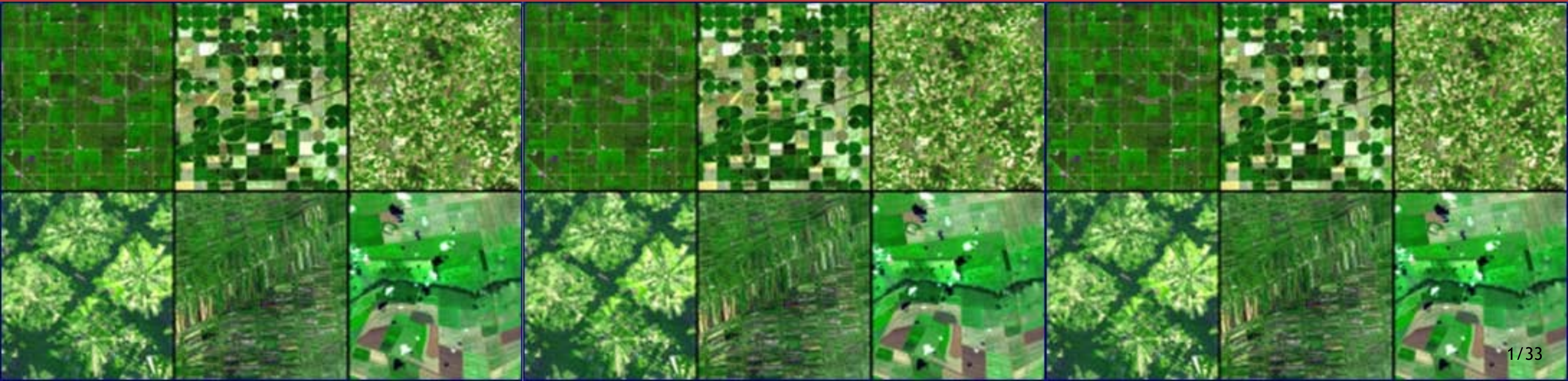
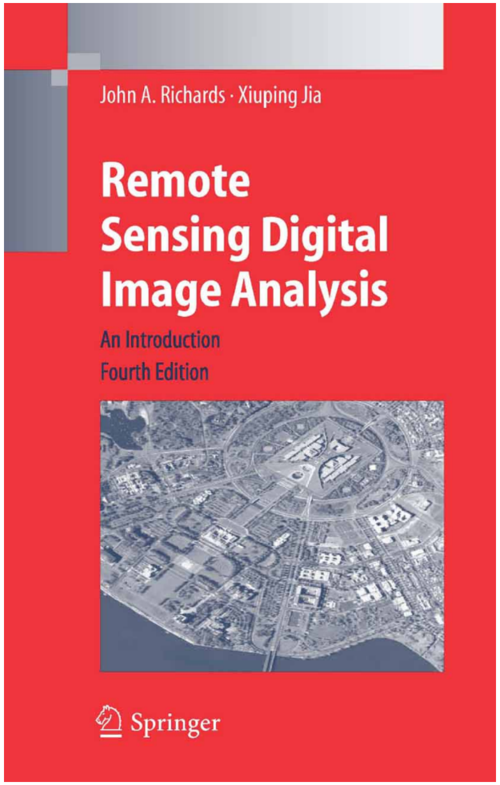
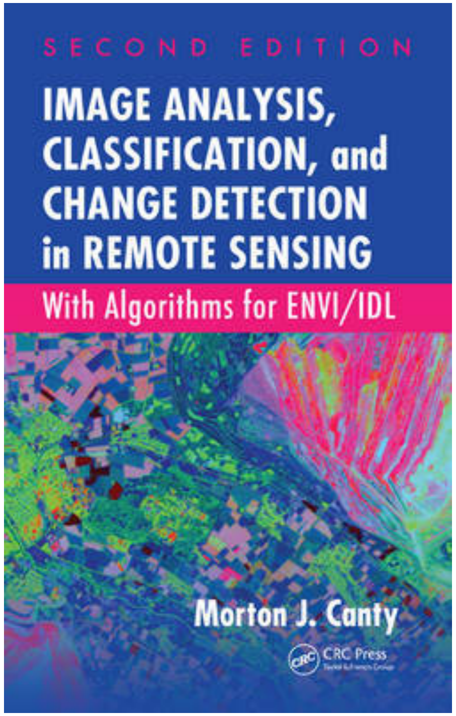
SOURCES AND CHARACTERISTICS OF “REMOTELY SENSED” IMAGE DATA

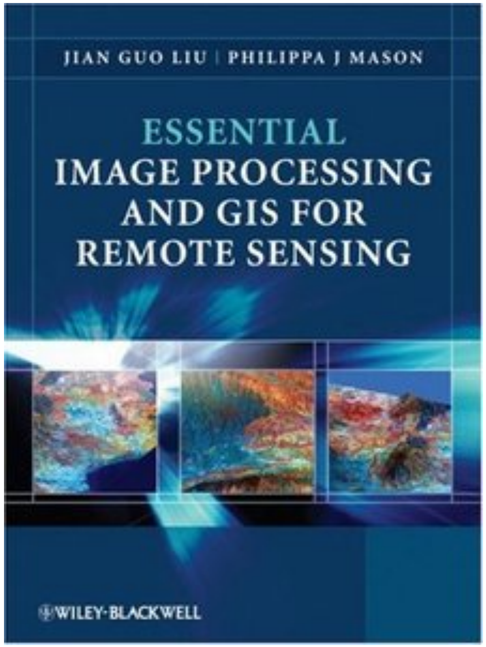


Suggested readings

- Remote Sensing Image Analysis domain

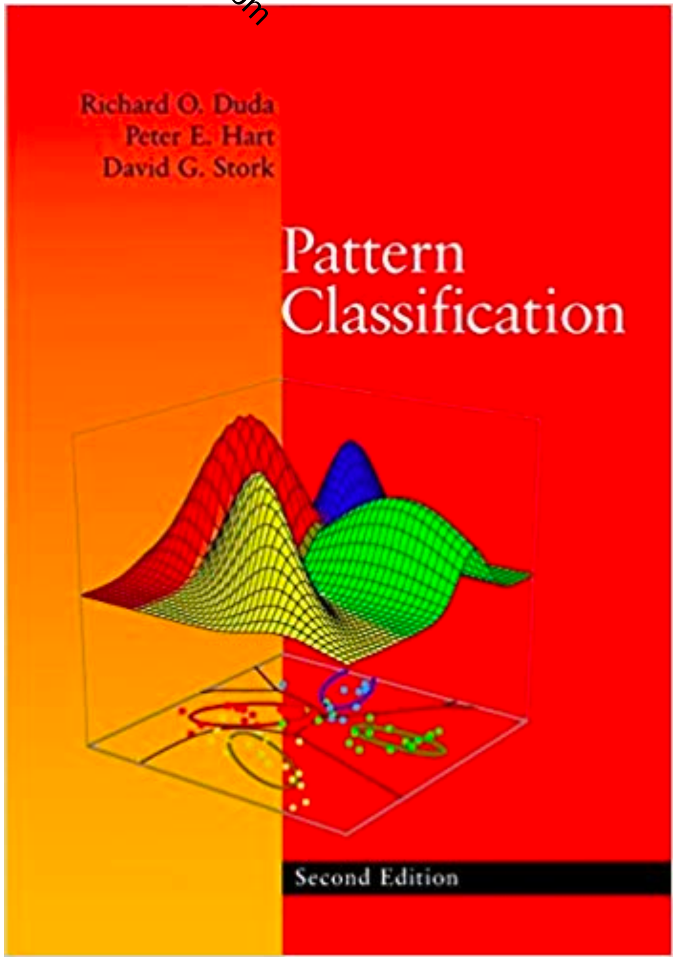


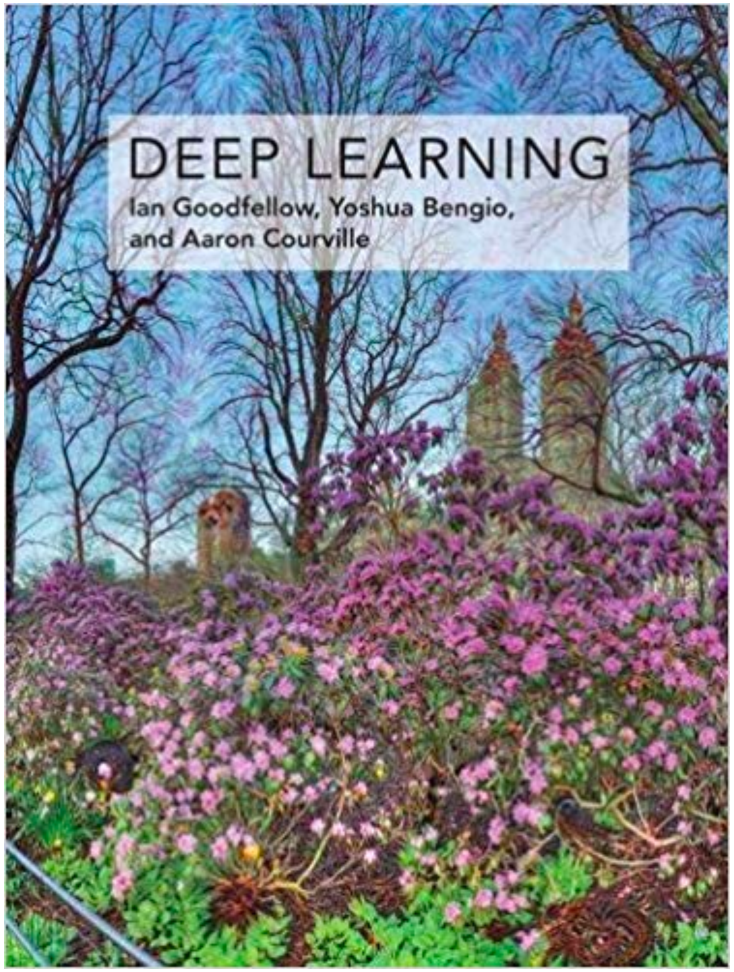




Suggested readings

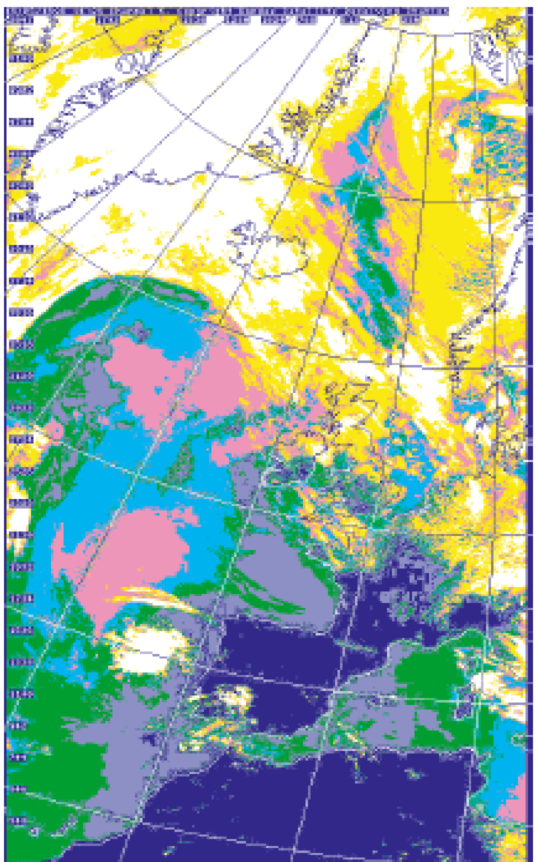
- Pattern Recognition (machine learning) and Deep Learning



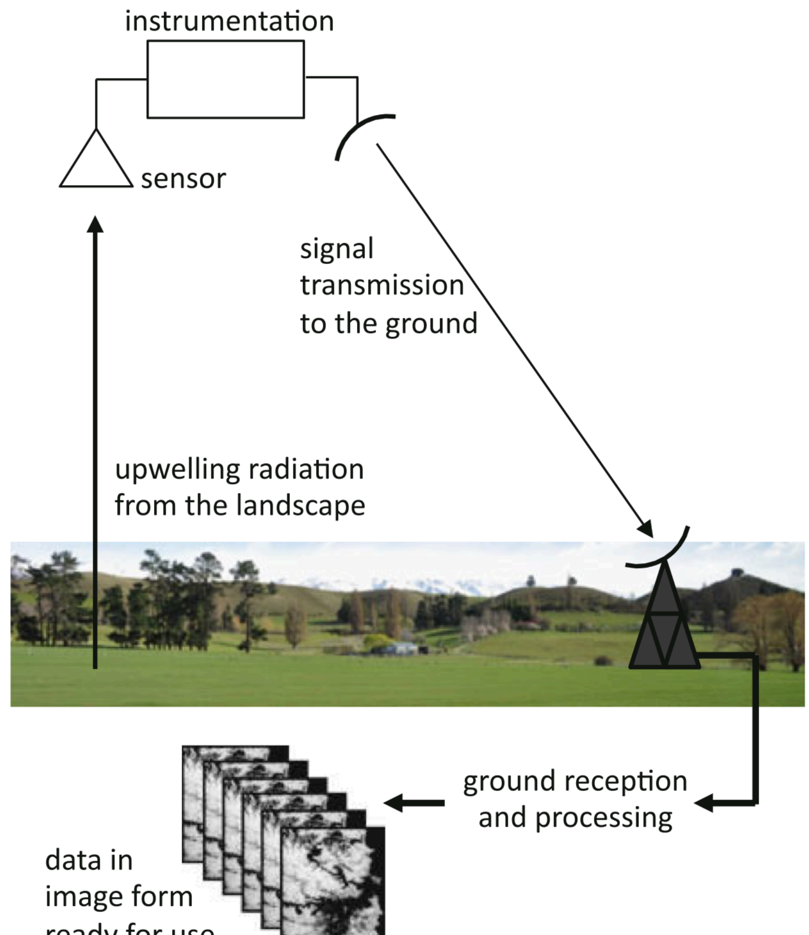


Introduction to Data Sources

- In **remote sensing** ***energy emanating from the earth's surface is measured*** using a sensor mounted on an aircraft or spacecraft platform.
- That measurement is ***used to construct an image of the landscape*** beneath the platform, as depicted in Figure



"map"



Characteristics of Digital Image Data

- **The energy**
  - can be ***reflected sunlight*** so that the image recorded is, in many ways, similar to the view we would have of the earth's surface from an airplane, although the *wavelengths* used in remote sensing *are often outside the range of human vision;*
  - can be from the ***earth itself acting as a radiator*** because of its own *temperature*;
  - can be ***scattered from the earth*** as the result of some ***illumination by an artificial energy source*** such as a *laser or radar carried on the platform*.

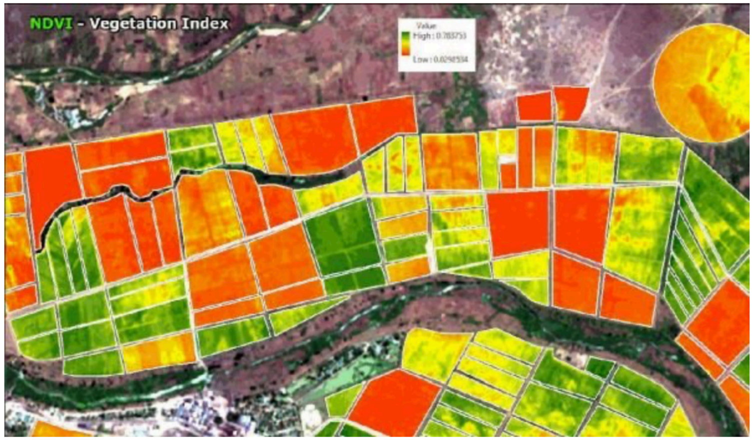
- ***The overall system is a complex one*** involving the *scattering* or emission of energy from the earth's surface, followed by *transmission* through the ***atmosphere*** to instruments mounted on the remote sensing platform, *transmission* or carriage of data back to the earth's surface after which it is then processed into ***image products*** ready for application by the user (photointerpreter)

- Acquired images and data are directly available in **digital** format
  - with a direct need to develop solutions for a (semi)automated analysis of their informative features and/or (un)supervised understanding of their content/meaning.

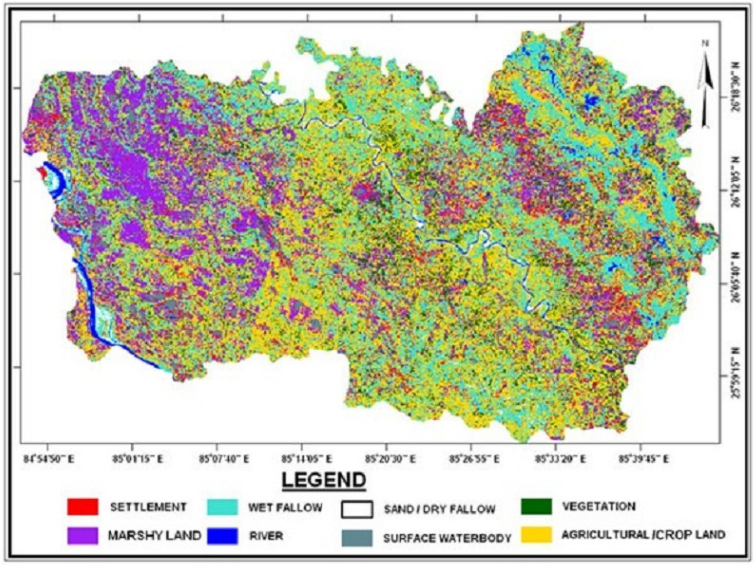
Remote Sensing data products and processing

Image maps
(direct visual interpretation)

Ratio/interval scale (parametric maps)

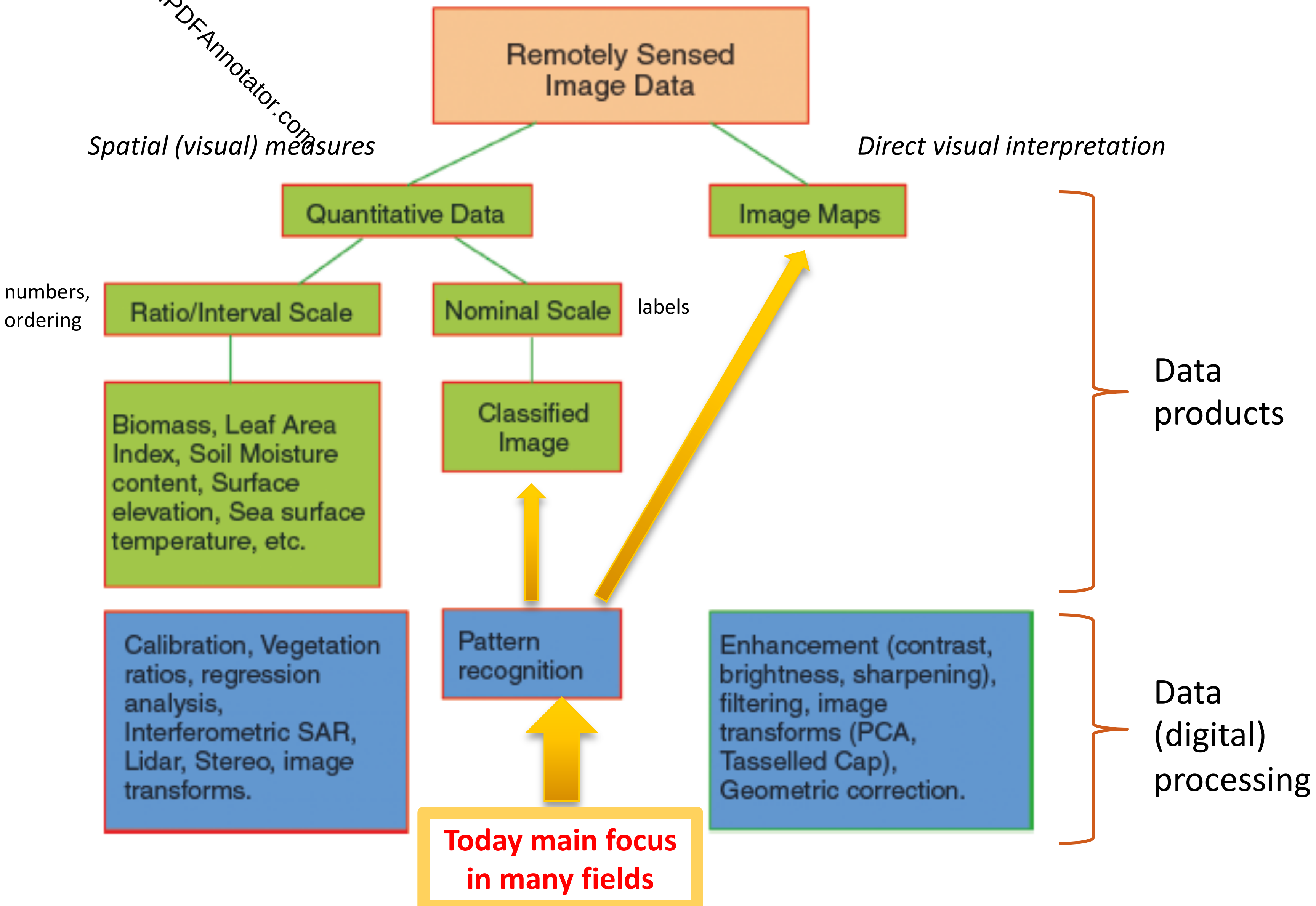


Normalized Difference Vegetation Index (NDVI) Scale Used



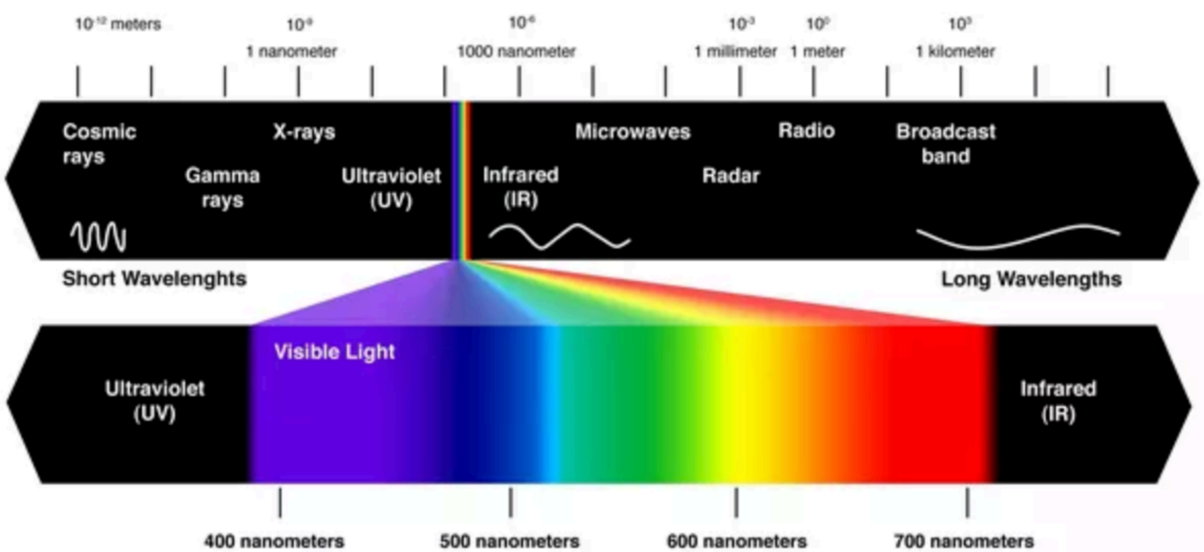
Nominal scale (labels, thematic maps)

Remote Sensing data products and processing



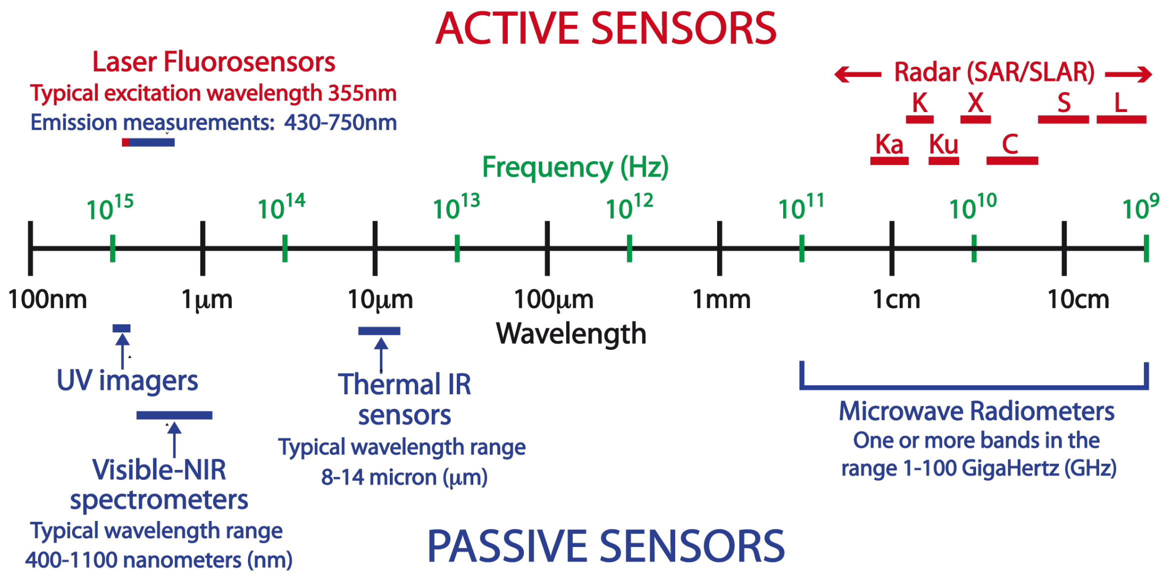
Wavelenghts of interest, active and passive systems

- The most significant characteristic of the image data in a remote sensing system is the **wavelength**, or range of wavelengths, used in the acquisition process.
  - If reflected solar radiation is measured, images can, in principle, be recorded in the *ultraviolet, visible and near-to-middle infrared range* of wavelengths.
  - Because of significant atmospheric absorption, *ultraviolet measurements are not made*.
  - Most common, so-called ***optical***, remote sensing systems *record data from the visible through to the near and mid infrared range*.
  - The energy emitted by the earth itself (dominant in the so-called *thermal infrared wavelength range)* can also be *resolved into different wavelengths* that help up understand the properties of the earth surface region being imaged.



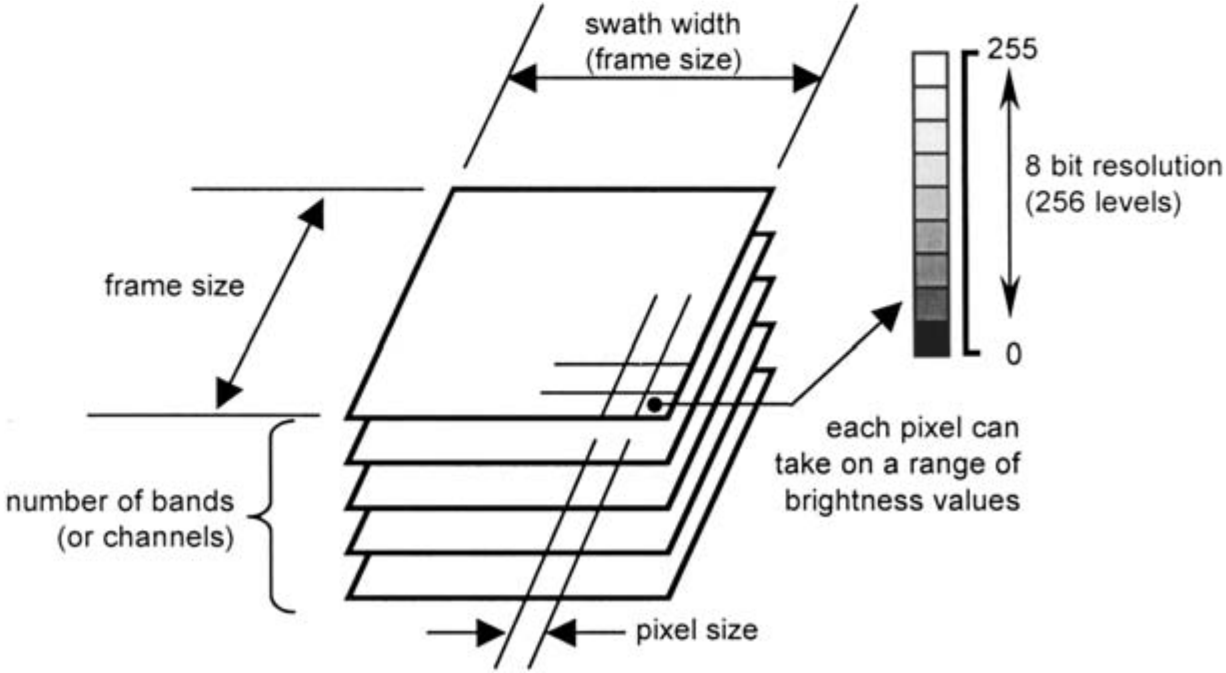
Wavelenghts of interest, active and passive systems

- The ***visible*** and ***infrared*** range of wavelengths represents only part of the story in remote sensing. We can also image the earth in the ***microwave range***, typical of the wavelengths used in mobile phone, television, FM and radar technologies.
  - The earth does emit its own level of microwave radiation, but this is generally too small to be measured for most remote sensing mapping purposes. Instead, *energy can be radiated from a platform onto the earth's surface*. It is by measuring the energy scattered back to the platform that image data is recorded. Such a system is referred to as ***active*** since the energy source is provided by the platform.
  - By comparison, remote sensing measurements that depend upon an energy source such as the sun or the earth itself are called ***passive***.



Technical characteristics of digital image data

- From a data handling and analysis point of view the properties of image data of significance are the number and location of the spectral measurements (called ***spectral bands*** or channels) provided by a particular sensor, the *spatial resolution* as described by the pixel size, and the *radiometric resolution*, as illustrated in Figure



- Together, the frame size of an image, in equivalent ground kilometres (which is determined by the size of the recorded image swath), the number of spectral bands, the radiometric resolution and the spatial resolution expressed in equivalent ground metres, determine the data volume generated by a particular sensor. That establishes the amount of data to be processed.

Spectral Ranges Commonly Used in Remote Sensing

- In principle, remote sensing systems could measure energy emanating from the earth's surface in any sensible range of wavelengths.
  - However technological considerations, the selective opacity of the earth's atmosphere, scattering from atmospheric particulates and the significance of the data provided *exclude certain wavelengths.*
  - The major ranges utilized for earth resources sensing are **between about 0.4 and 12 µm** (the **visible/infrared range**) and between about 30 to 300 mm (the microwave range).
  - At microwave wavelengths it is often more common to use frequency rather than wavelength to describe ranges of importance. Thus the **microwave range** of 30 to 300 mm corresponds to **frequencies between 1 GHz and 10 GHz**.
  - For atmospheric remote sensing, frequencies in the range 20 GHz to 60 GHZ are encountered.
- **The significance of these different ranges lies in the interaction mechanism between the electromagnetic radiation and the materials being examined.**
  - In the **visible/infrared range** the energy measured by a sensor depends upon properties such as the ***pigmentation, moisture content and cellular structure of vegetation, the mineral and moisture contents of soils and the level of sedimentation of water***.
  - At the **thermal end of the infrared range** it is ***heat capacity and other thermal properties of the surface and near subsurface*** that control the strength of radiation detected.
  - In the **microwave range**, using active imaging systems based upon radar techniques, the ***roughness of the cover type being detected and its electrical properties***, expressed in terms of complex permittivity (which in turn is strongly influenced by moisture content) determine the magnitude of the reflected signal.
  - In the **range 20 to 60 GHz**, ***atmospheric oxygen and water vapor*** have a strong effect on transmission and thus can be inferred by measurements in that range.
- **In other fields we can use other wavelengths (e.g. X-rays) for other goals (e.g. tissue density measures)**

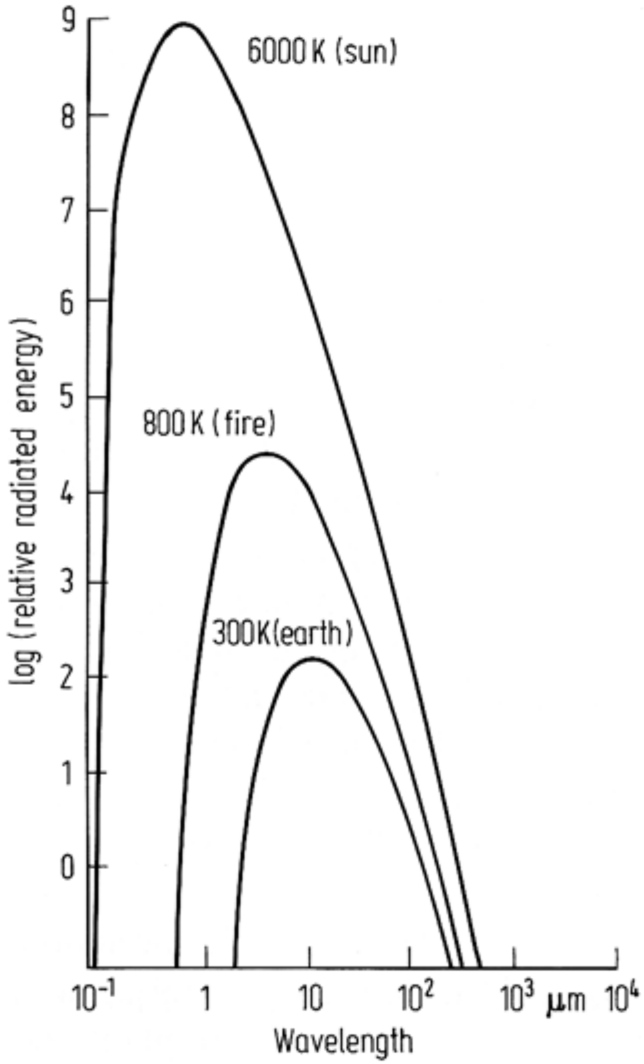
Spectral Ranges Commonly Used in Remote Sensing

Remarks

- The purpose of acquiring remote sensing image data is to be able to identify and assess, by some means, surface materials and their spatial properties. Inspection of the Figure of spectral reflectance reveals that **cover type identification should be possible if the sensor gathers data at several wavelengths**.
  - **For example**, if for each pixel, measurements of reflection at 0.65 µm and 1.0 µm were available (i.e. we had a two band imaging system) then it should be a relatively easy matter to discriminate between the three fundamental cover types based on the relative values in the two bands. For example, vegetation would be bright at 1.0 µm and very dark at 0.65µm whereas soil would be bright in both ranges. Water on the other hand would be black at 1.0 µm and dull at 0.65 µm.
- Clearly if more than two measurement wavelengths were used more precise discrimination should be possible, even with cover types spectrally similar to each other.
- Consequently remote sensing imaging systems are designed with wavebands that take several samples of the spectral reflectance curves.
  - For each pixel the set of samples can be analysed, either by *photointerpretation*, or by the *automated techniques* that we will see, to provide a label that associates the pixel with a particular earth surface material.

Radiation energy from different hot bodies

- Figure shows the relative amount of **energy radiated** from perfect black bodies of different temperatures.
  - The **sun** at **6000K** radiates maximally in the **visible and near infrared** regime but by comparison generates *little radiation in the range around 10 µm*. The figure does not take any account of how the level of solar radiation is dispersed through the *inverse square law* process in its travel from the sun to the earth. Consequently if it is desired to compare that curve to others corresponding to black bodies on the earth's surface then it should be appropriately reduced (see next slide).
  - The **earth**, at a temperature of about **300 K** has its maximum emission **around 10 to 12 µm**. Thus a *sensor with sensitivity in this range will measure the amount of heat being radiated from the earth itself*.
  - **Hot bodies** on the earth's surface, such as bushfires, at around **800 K**, have a maximum emission in the range of about **3 to 5 µm**. Consequently to map fires, a sensor operating in that range would be used.
  - *Real objects do not behave as perfect black body radiators but rather emit energy at a lower level* than that shown in Figure. The degree to which an object radiates by comparison to a black body is referred to as its *emittance*.
  - *Thermal remote sensing is sensitive therefore to a combination of an object's temperature and emittance, the last being wavelength dependent.*



Electromagnetic radiation scattering

- **Microwave remote sensing** image data is gathered by measuring the strength of energy scattered back to the satellite or aircraft in response to energy transmitted.
  - The degree of reflection is characterized by the ***scattering coefficient*** for the surface material being imaged. This is **a function of the electrical complex permittivity of the material and the roughness of the surface** in comparison to the wavelength of the radiation used.

1. **Smooth surfaces** act as so-called specular reflectors (i.e. mirror-like) in that the direction of scattering is predominantly away from the incident direction as shown in Figure (a). Consequently they appear *dark to black in image data*.
2. **Rough surfaces** act as diffuse reflectors; they scatter the incident energy in all directions as depicted in Figure (b), including back towards the remote sensing platform. As a result they appear *light in image data*.
3. A third type of surface scattering mechanism is often encountered in microwave image data, particularly associated with **manufactured features** such as buildings. This is a corner reflector effect, as seen in Figure (c), resulting from the right angle formed between a vertical structure such as a fence, building or ship and a horizontal plane such as the surface of the earth or sea. This gives a *very bright response*.
4. Media, such as vegetation canopies and sea ice, exhibit so-called ***volume scattering*** behavior, in that backscattered energy emerges from many, hard to define sites within the volume, as depicted in Figure (d). This leads to a *light tonal appearance in radar imagery*.

Electromagnetic radiation scattering (contd)

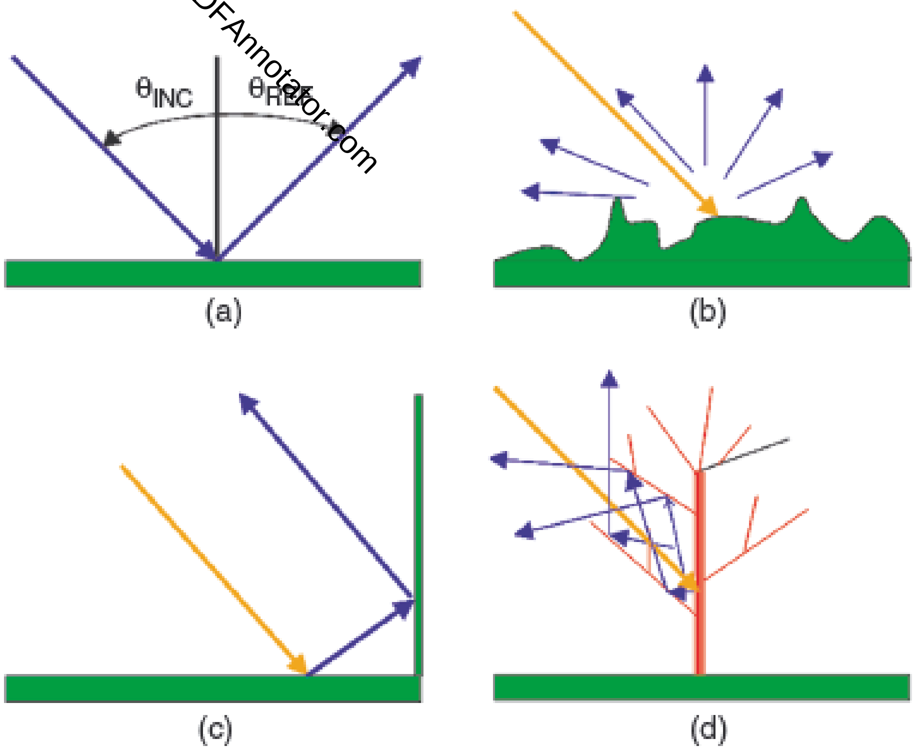


FIGURE *Types of scattering of electromagnetic radiation. (a) Specular, in which incident radiation is reflected in the forward direction, (b) Lambertian, in which incident radiation is equally scattered in all upward directions, (c) corner reflector, which acts like a vertical mirror, especially at microwave wavelengths and (d) volume scattering, in which (in this example) branches and leaves produce single-bounce (primary) and multiple-bounce (secondary) scattering.*

- In interpreting image data acquired in the microwave region of the electromagnetic spectrum it is important to recognise that the four reflection mechanisms of Figure are present and that *the tonal differences are also* ***modulated*** *by 1)* ***wavelength*** *and 2) surface* ***complex permittivity*** *variations (e.g. due to moisture)*.

- By comparison, imaging in the visible/infrared range in which the sun is the energy source, results almost always from diffuse reflection, *allowing the interpreter to concentrate on tonal variations resulting from factors such as those described, in association with spectral reflectance curves*.

Electromagnetic radiation scattering (contd)

Band	Typical wavelength (cm)	Frequency (GHz)
P	66.7	0.45
L	23.5	1.28
S	12.6	2.38
C	5.7	5.3
X	3.1	9.7
Ku	2.16	13.9

Wavelength in metres and frequency in megahertz are related by the expression $f(\mathrm{MH_z}) = 300/\lambda(m)$

TABLE Typical radio wavelengths and corresponding frequencies used in radar remote sensing, based on actual missions; only the lower end of the K band is currently used

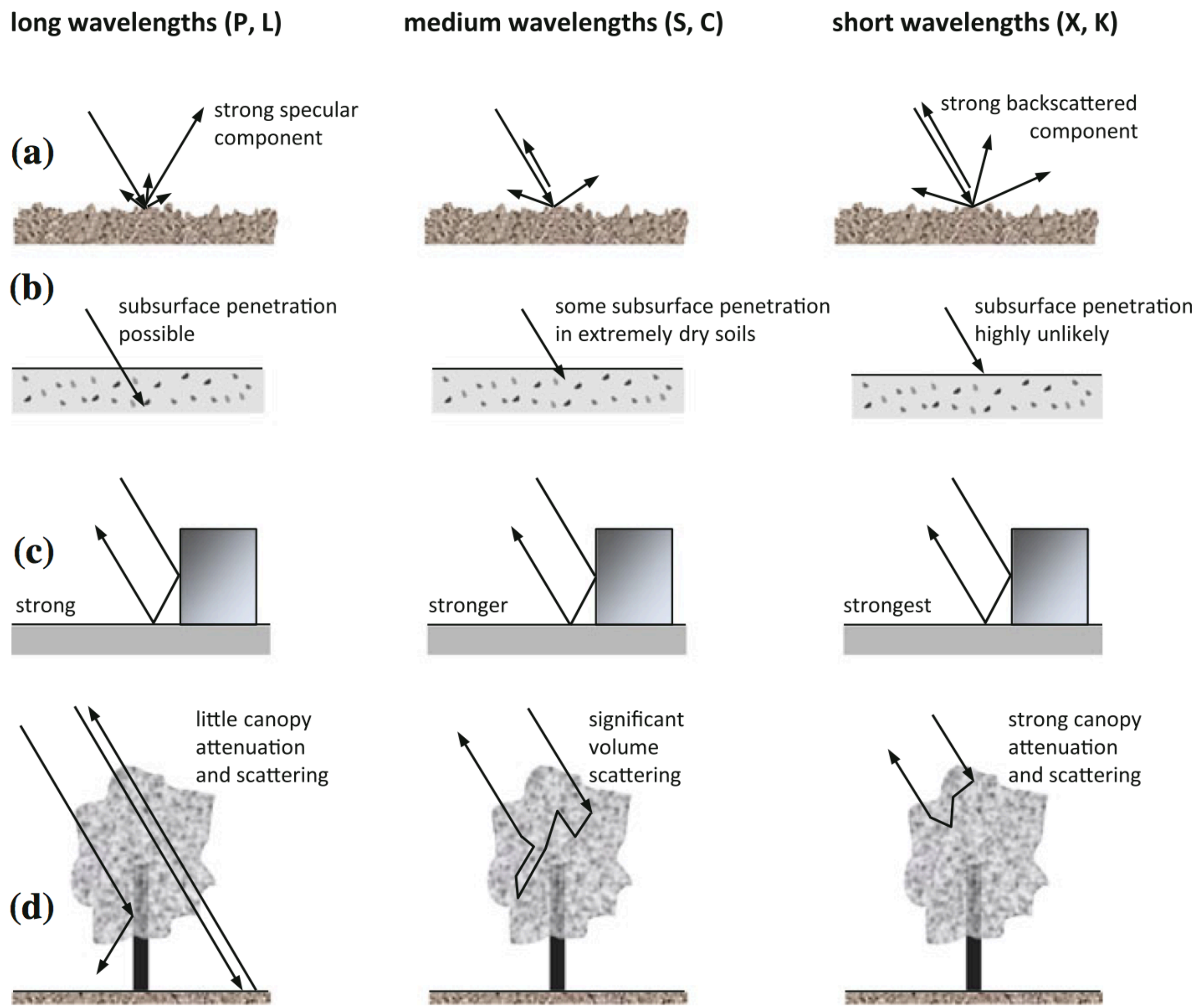


FIGURE Common radar scattering mechanisms as a function of the wavelength of the irradiating energy **a** surface, **b** sub-surface, **c** corner reflector, and **d** volume scattering

REMOTE SENSING PLATFORMS

Different kind of platforms and applications

- Imaging in remote sensing can be carried out from both **satellite** and **aircraft** platforms. In many ways their sensors have ***similar characteristics although differences in their altitude and stability can lead to very different image properties***.

- There are essentially two broad classes of satellite program:

1. those satellites that sit at ***geostationary*** altitudes (35.786 km) above the earth's surface and which are generally associated with weather and climate studies,
2. and those which orbit much closer to the earth's surface (***low earth orbits, LEO*** with altitudes between about 150 and 2000 km) that are generally used for earth surface and oceanographic observations (e.g. Landsat altitudes are 705 km).

- Usually, the LEO satellites are in a ***sun-synchronous*** orbit, in that their orbital plane precesses around the earth at the same rate that the sun appears to move across the earth's surface (see figure in the next slide). In this manner the satellite acquires data at about the same local time on each orbit.
  - LEO satellites can also be used for meteorological studies.

Different kind of platforms and applications

- Notwithstanding the differences in altitude, the ***wavebands*** used for the geostationary and the low earth orbiting satellites, and for weather and earth observation satellites, are *very comparable*.

- *The major distinction* in the image data they provide generally lies in the ***spatial resolutions*** available.
  - data acquired for earth resources purposes generally has pixel sizes of *less than 100 m*,
  - that used for meteorological purposes (both at geostationary and lower altitudes) has a much coarser pixel, often of the *order of 1 km*.

- For a technical deepening on satellite missions see
  - The course of Remote Sensing Data Acquisition
  - Appendix A (on textbook, 4° edition only)
  - NASA, Terra Landsat and other satellite mission websites
    - https://terra.nasa.gov
    - https://landsat.gsfc.nasa.gov
    - https://landsat.usgs.gov
    - ...

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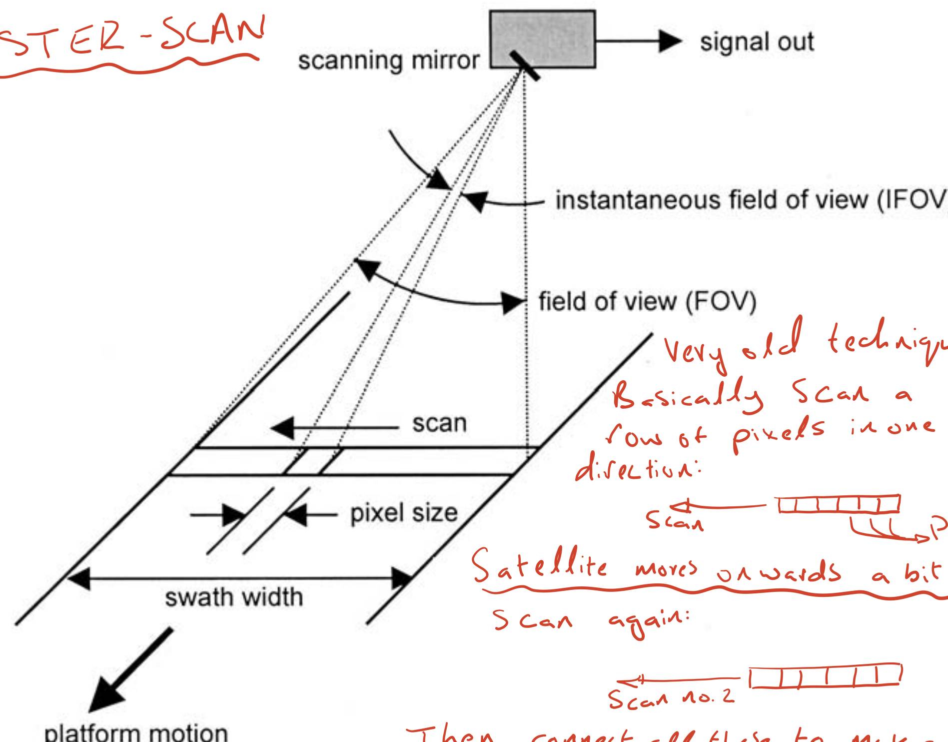
Satellite and aircraft imaging technologies

- The imaging technologies utilised in satellite programs record images of the earth's surface by moving the instantaneous field of view of the instrument across the earth's surface to record energy.
  - Some weather satellites scan the earth's surface using the *spin of the satellite itself* while the sensor's pointing direction is varied (at a slower rate) along the axis of the satellite. The image data is then recorded in a raster-scan fashion not unlike that used for the production of television pictures.
- A more common image recording mechanism, used in the Landsat program, has been to carry a ***mechanical scanner that records at right angles to the direction of the satellite motion to produce raster-scans of data***. The forward motion of the vehicle then allows an image strip to be built up from the raster-scans. That process is depicted in Figure.

RASTER-SCAN

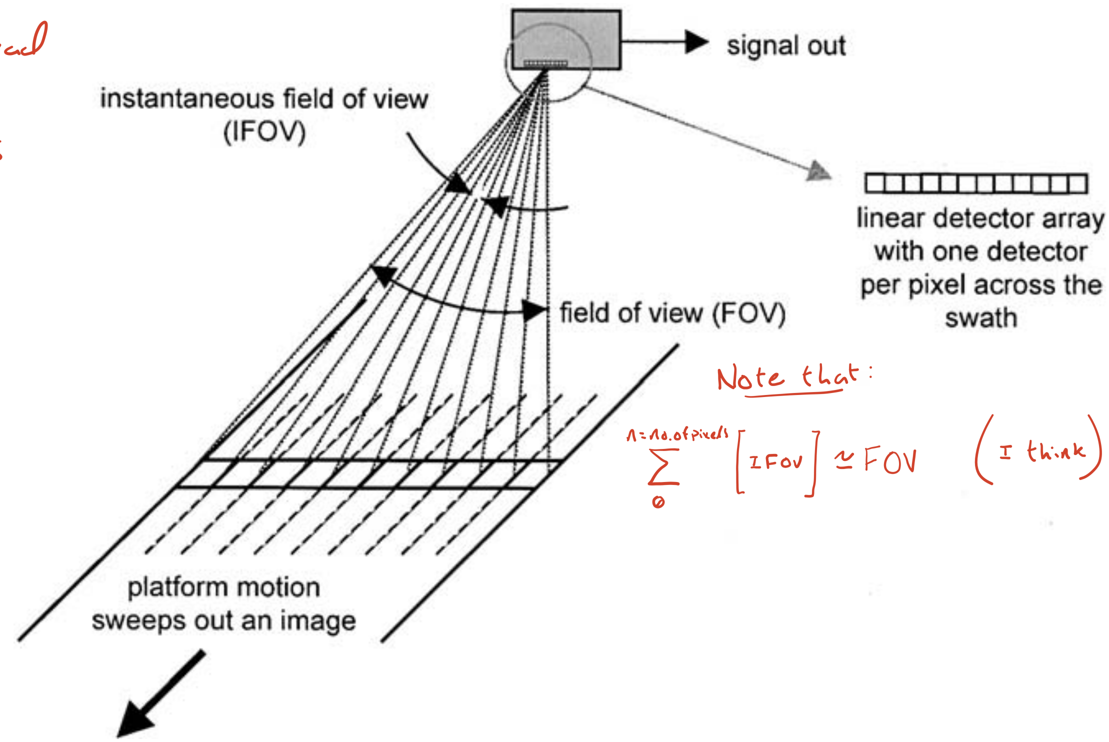


Very old technique.
Basically Scan a row of pixels in one direction:
Scan
Pixels
Satellite moves onwards a bit...
Scan again:
Scan no. 2
Then connect all these to make a map.

Satellite and aircraft imaging technologies

- More recent technology utilizes a “push-broom" mechanism in which a ***linear imaging array with sufficient detectors is carried on the satellite, normal to the satellite’s motion***, such that each pixel can be recorded individually.
  - The forward motion of the satellite then allows subsequent pixels to be recorded along the satellite travel direction in the manner shown in Figure.
  - As might be expected, the time over which *the energy emanating from the earth’s surface per pixel is larger* with push broom scanning than for the mechanical scanners, generally ***allowing finer spatial resolutions*** *to be achieved*.

Similar to before but now instead of one pixel which is "scanned"/tracked it is now a <u>line</u> of pixels which is stationary.

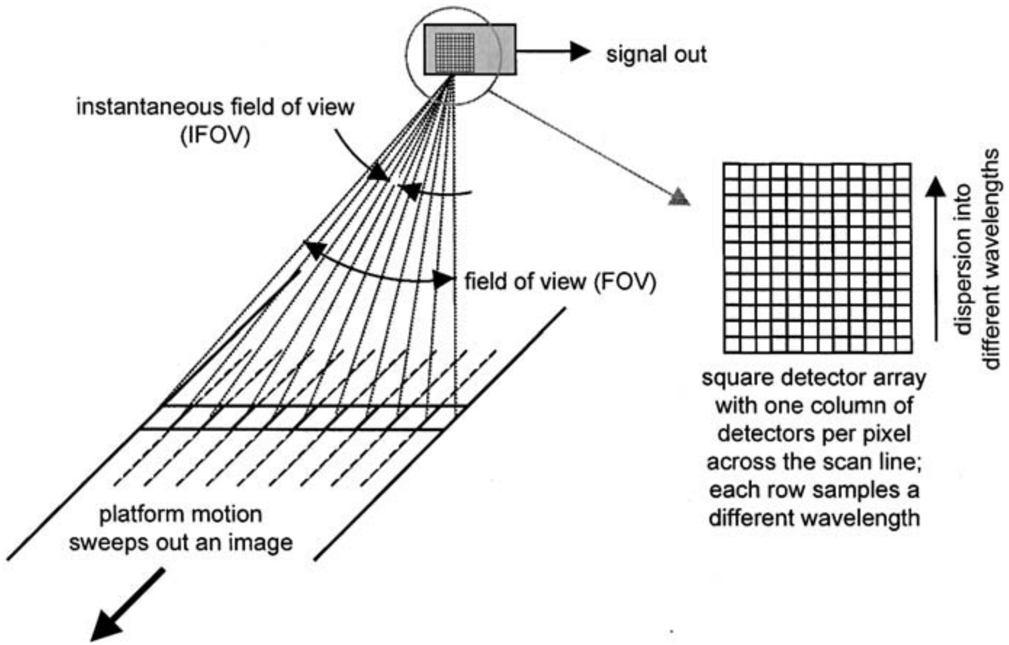


Note that:

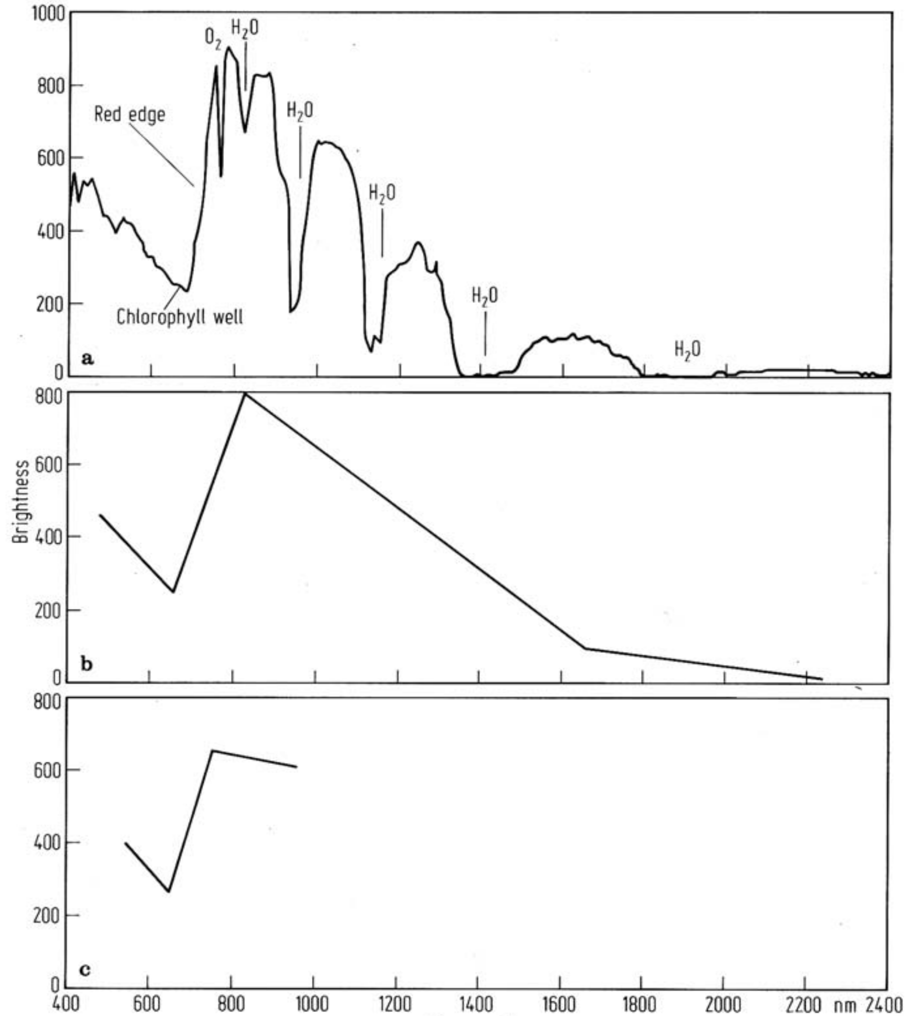
$$\sum_{0}^{n=\text{no. of pixels}} \left[\text{IFOV}\right] \simeq \text{FOV}$$ (I think)

Satellite and aircraft imaging technologies

- Aircraft scanners operate with essentially the same principles as those found on satellites.
  - Both mechanical scanners (often utilising rotating mirrors) and CCD arrays are commonly employed.
  - An interesting development employ **rectangular detector arrays** which, in principle, could be used to capture a two-dimensional image underneath the satellite. They are normally **used, however, to record pixels in the across track direction**, as with push broom scanners, **with the other dimension employed to record many spectral channels of data simultaneously**, as depicted in Figure.
  - Often *as many as 200 or so channels are recorded* in this manner so that a very good rendition of the spectra can be obtained. As a result the devices are often referred to as imaging spectrometers and the data described as **hyperspectral**, as against multispectral when of the order of 10 wavebands are recorded (es. *AVIRIS instrument*).



Spectral resolution: conventional vs spectrometric imaging

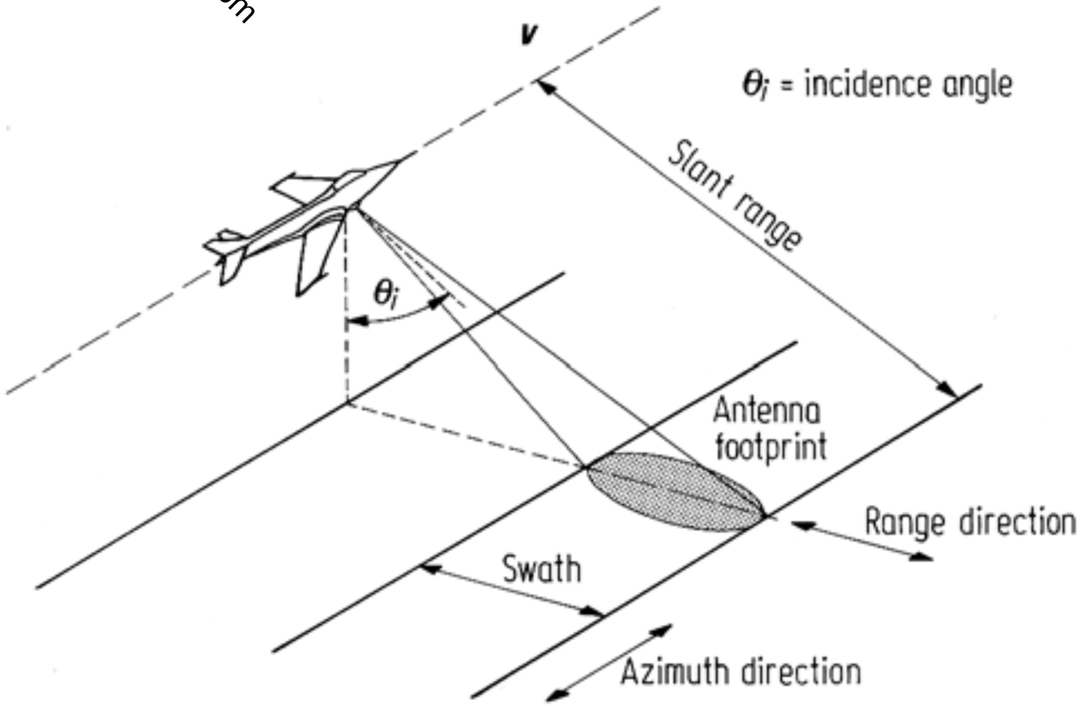


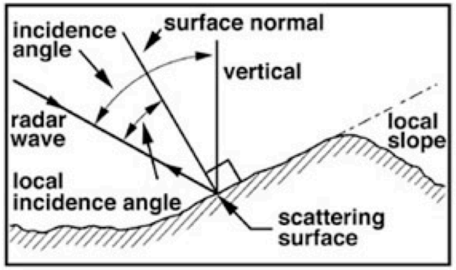
- Vegetation spectrum recorded by AVIRIS at 10 nm spectral sampling (a), along with equivalent Thematic Mapper TM (b) and Multispectral Scanner MSS (c) spectra. In (a) the fine absorption features resulting from atmospheric constituents are shown, along with features normally associated with vegetation spectra.

IMAGE DATA SOURCES IN THE MICROWAVE REGION

Side Looking Airborne Radar (SLAR)

- Remote sensing image data in the microwave range of wavelengths is generally gathered using the technique of **side-looking radar**, as illustrated in Figure.





- When used with aircraft platforms it is more commonly called **SLAR** (side looking airborne radar), a technique that requires some modification when used from spacecraft altitudes, as discussed in the following.

Side Looking Airborne Radar (SLAR)

- In SLAR a pulse of electrical energy at the microwave frequency (or wavelength) of interest is radiated to the side of the aircraft at an incidence angle of ϑ_i.
  - *By the* same principle as radars used for air navigation and shipping, *some of this transmitted energy is scattered from the ground and returned to the receiver* on the aircraft.
  - The time delay between transmission and reflection identifies the *slant distance to the "target" from the aircraft*, while the *strength of the return* contains information on the so-called scattering coefficient of the target region of the earth's surface.
  - The actual received signal from a single transmitted pulse consists of a continuum of reflections from the complete region of ground actually illuminated by the radar antenna. In Figure this can be identified as the ***range beamwidth of the antenna***. This is chosen at design to give a relation between swath width and altitude, and *tends to be rather broad*.
  - By comparison the ***along-track, or so-called azimuth, beamwidth*** *is chosen as small as possible* so that the reflections from a single transmitted pulse can be regarded as having come from a *narrow strip of terrain* broadside to the aircraft.
  - ***The forward velocity*** of the aircraft is then arranged so that the next transmitted pulse illuminates the next strip of terrain along the swath. In this manner the azimuth beamwidth of the antenna defines the **spatial resolution in the azimuth direction**
  - ***The time resolution*** possible between echos from two adjacent targets in the range direction defines the **spatial resolution in the slant direction**.

Side Looking Airborne Radar (SLAR)

- From an image product viewpoint the *slant range resolution* is not of interest. Rather it is the *projection of this onto the horizontal plane as* ***ground range resolution*** that is of value to the user.
- *The ground range resolution is better at larger incidence angles* and thus on the far side of the swath; it can be shown that the ground range size of a resolution element (pixel) is given by

$$r_g = c\tau/(2 \sin \vartheta_i)$$

where τ is the length of the transmitted pulse and c is the velocity of light. (*)
- *Often simple pulses are not used. Chirped waveforms are used instead with some associated signal processing* (data acquisition course).
- The *azimuth size of a resolution element* is related to the length (or aperture) of the transmitting antenna in the azimuth direction, l, the wavelength λ and the range R_0 between the aircraft and the target, and is given by

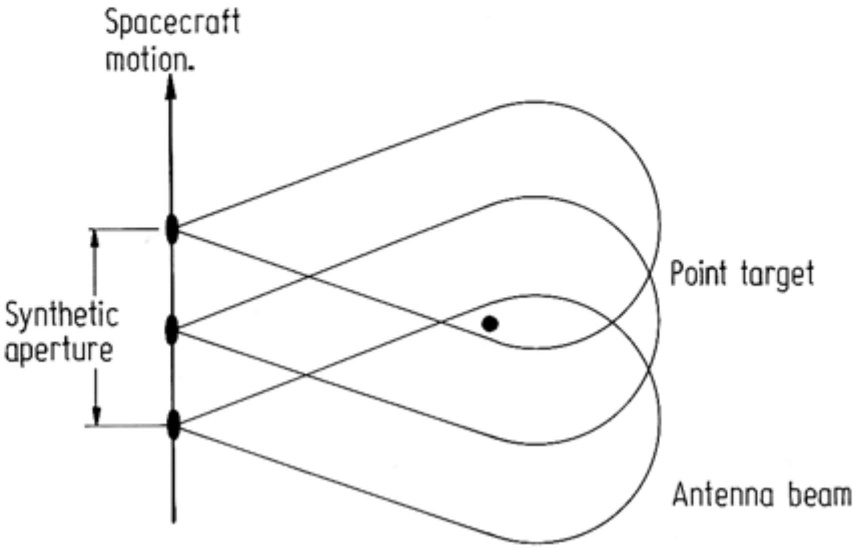
$$r_a = R_0 \lambda / l$$

- This expression shows that a 10 m antenna will yield an azimuth resolution of 20m at a slant range of 1 km for radiation with a wavelength of 20 cm. However, if the slant range is increased to say 100 km – i.e. at low spacecraft altitudes – then a 20 m azimuth resolution would require an antenna of 1 km length, which clearly is impracticable.

(*) the shorter the pulse, the shorter the distance (temporal and spatial) between two detectable echoes (but the lower the power and thus SNR). Pulse modulation can be used to increase ground range resolution.

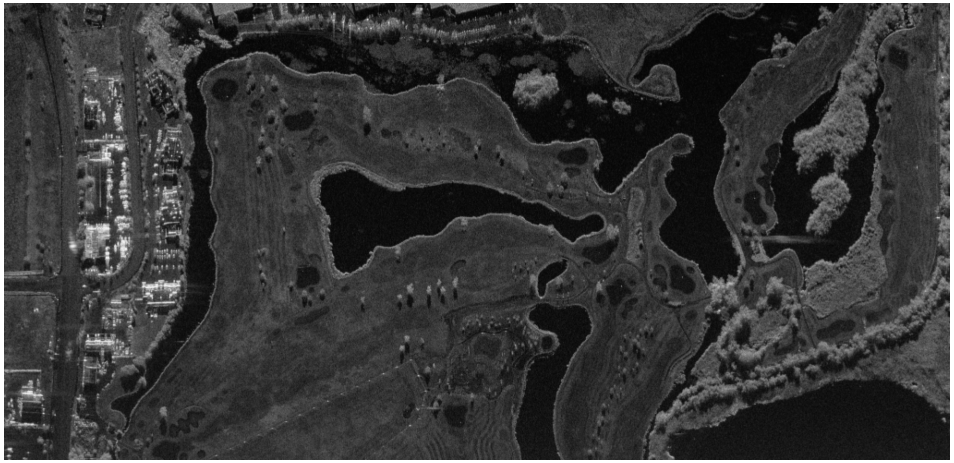
Synthetic Aperture Radar (SAR)

- Due to the above problem when radar image data is to be acquired from spacecraft, a modification of SLAR referred to as **synthetic aperture radar (SAR)** is used.
- Essentially this utilizes the motion of the space vehicle, during transmission of the ranging pulses, to give an effectively long antenna, or a so-called synthetic aperture.



- This principle is illustrated in Figure, wherein it is seen that an intentionally large azimuth beamwidth is employed to ensure that a particular spot on the ground is illuminated and thus provides reflections over a length of spacecraft travel equivalent to the synthetic aperture required.
- A view from above is shown, illustrating that a small real antenna is used to ensure a large real beamwidth in azimuth. Target point on the ground is illuminated by the full synthetic aperture and post-processing is used to better resolve elements in the target region

Synthetic Aperture Radar (SAR)



Examples of various SAR images in different bands

SPATIAL DATA SOURCES IN GENERAL

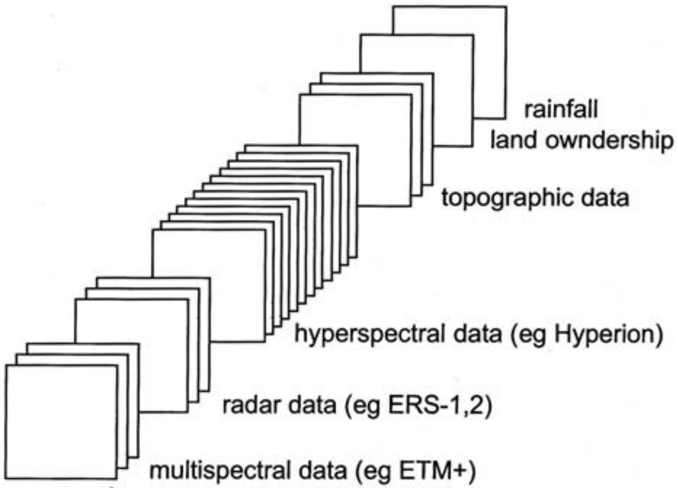
Types of Spatial Data

- We have addressed sources of multispectral digital image data. Other sources of spatially distributed data are also often available for regions of interest.
  - These include simple ***maps*** that show topography, land ownership, roads and the like, through to more specialised sources of spatial data such as maps of geophysical measurements of the area.
  - Frequently these other spatial data sources contain information not available in multispectral imagery and often judicious *combinations* of multispectral and other map-like data allow inferences to be drawn about regions on the earth's surface not possible when using a single source on its own.
  - Consequently the image analyst ought to be aware of the range of spatial data available for a region and select that subset likely to assist in the information extraction process.
- Sources of spatial data (information can be associated to points, lines or areas)

Point	Line	Area
Multispectral data	road maps	land ownership
Topography	powerline grids	town plans
Magnetic measurements	pipeline networks	geological maps
Gravity measurements		land use licenses
Radiometric measurements		land use maps
Rainfall		land cover maps
Geochemistry (in ppm)		soil type maps

Types of Spatial Data

- Irrespective of type (point, line, area), for a spatial data set to be manipulated using the techniques of digital image processing it must share two characteristics with multispectral data.
  - First it must be available in discrete form spatially, and in value. In other words it must consist of, or be able to be converted to, pixels with each pixel describing the properties of a given (small) area on the ground: the value ascribed to each pixel must be expressible in digital form.
  - Secondly it must be in *correct geographic relation* to a multispectral image data set if the two are to be manipulated together. In situations where multispectral data is not used, the pixels in the spatial data source would normally be arranged to be referenced to a map grid.
- It is usual however, in digital spatial data handling systems, to have all entries in the data set relating to a particular geographical region, mutually registered and referenced to a map base such as the UTM grid system. When available in this manner the data is said to be **geocoded**.



Data Formats

- Sometimes the data will be available as analog maps that require digitisation before entry into a digital data base. That is particularly the case with line and area data types, in which case consideration has to be given also to the "value" that will be ascribed to a particular pixel.
  - For a road map, for example, pixels that fall on highways might be given a value of 1 whereas those on secondary roads could be given a value of 2, and so on.
- Consider the case for example (in figure), of needing to create a digital topographic map from its analog contour map counterpart.
  - Some spatial data handling computer systems operate in vector format entirely.
  - However to be able to exploit the techniques of digital image processing the vector formatted data has to be turned into a set of pixels arranged on rectangular grid centres (raster format).