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Introduction to Remote Sensing of Biomass

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1. Introduction

Planet Earth is distinguished from other Solar System planets by two major categories: Oceans and Land Vegetation. The oceans cover ~70% of the Earth's surface; land comprises 30%. On the land itself, the first order categories break down as follows: Trees = 30%; Grasses = 30%; Snow and Ice = 15%; Bare Rock = 18%; Sand and Desert Rock = 7%. Remote sensing has proven a powerful "tool" for assessing the identity, characteristics, and growth potential of most kinds of vegetative matter at several levels (from biomes to individual plants). Vegetation behaviour depends on the nature of the vegetation itself, its interactions with solar radiation and other climate factors, and the availability of chemical nutrients and water within the host medium (usually soil, or water in marine environments). A common measure of the status of a given plant, such as a crop used for human consumption, is its potential productivity (one such parameter has units of bushels/acre or tons/hectare, or similar units). Productivity is sensitive to amounts of incoming solar radiation and precipitation (both influence the regional climate), soil chemistry, water retention factors, and plant type, keeping in mind that various remote sensing systems (e.g., meteorological or earth-observing satellites) can provide inputs to productivity estimation.

Remote sensing can be broadly defined as *the collection and interpretation of information about an object, area, or event without being in physical contact with the object.* Aircraft and satellites are the common platforms for remote sensing of the earth and its natural resources. Aerial photography in the visible portion of the electromagnetic wavelength was the original form of remote sensing but technological developments has enabled the acquisition of information at other wavelengths including near infrared, thermal infrared and microwave. Collection of information over a large numbers of wavelength bands is referred to as multispectral or hyperspectral data. The development and deployment of manned and unmanned satellites has enhanced the collection of remotely sensed data and offers an inexpensive way to obtain information over large areas. The capacity of remote sensing to identify and monitor land surfaces and environmental conditions has expanded greatly over the last few years and remotely sensed data will be an essential tool in natural resource management.

1.1 Electromagnetic energy

The **electromagnetic (EM) spectrum** is the continuous range of electromagnetic radiation, extending from gamma rays (highest frequency & shortest wavelength) to radio waves (lowest frequency & longest wavelength) and including visible light.

The EM spectrum can be divided into seven different regions —— gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves and radio waves.

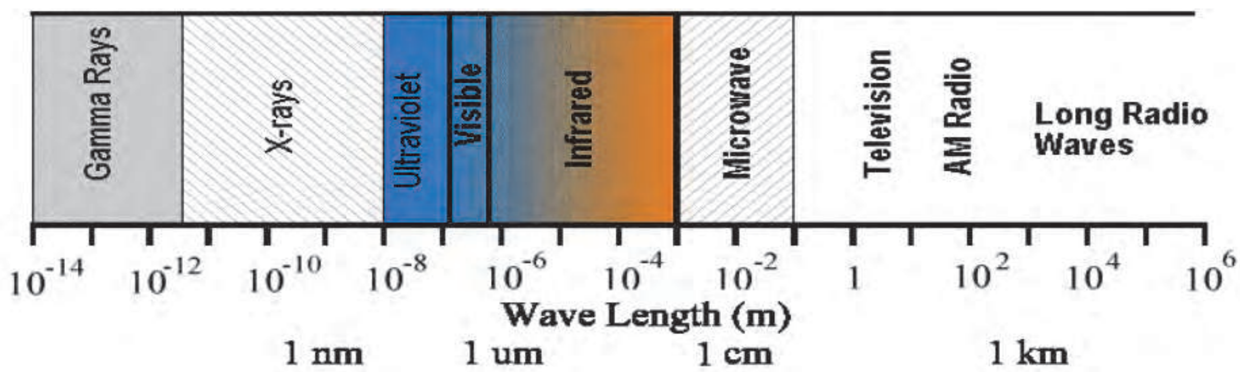


Fig. 1. Electromagnetic radiation spectrum

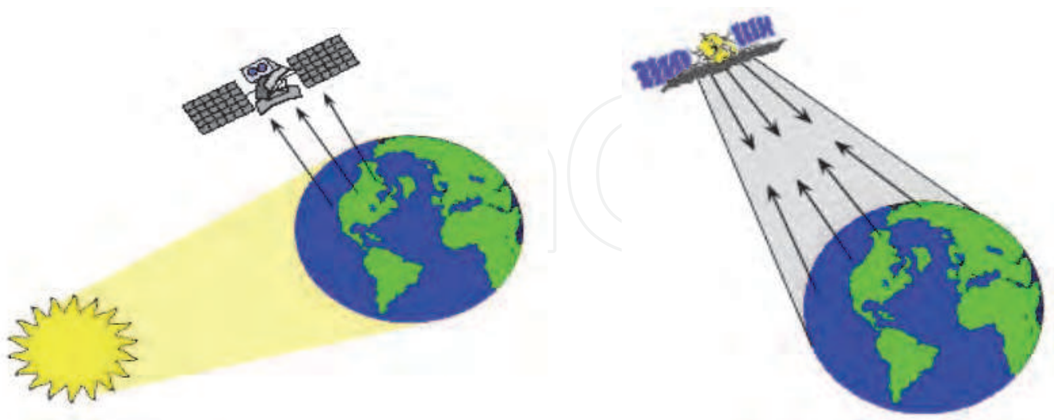
Remote sensing involves the measurement of energy in many parts of the electromagnetic (EM) spectrum. The major regions of interest in satellite sensing are visible light, reflected and emitted infrared, and the microwave regions. The measurement of this radiation takes place in what are known as **spectral bands.** A spectral band is defined as a discrete interval of the EM spectrum. For example the wavelength range of 0.4μm to 0.5μm **(μm = micrometers or 10-6m)** is one spectral band. Satellite sensors have been designed to measure responses within particular spectral bands to enable the discrimination of the major Earth surface materials. Scientists will choose a particular spectral band for data collection depending on what they wish to examine.
The design of satellite sensors is based on the absorption characteristics of Earth surface materials across all the measurable parts in the EM spectrum.

1.2 Reflection and absorption

When radiation from the Sun reaches the surface of the Earth, some of the energy at specific wavelengths is absorbed and the rest of the energy is reflected by the surface material. The only two exceptions to this situation are if the surface of a body is a perfect reflector or a true black body. The occurrence of these surfaces in the natural world is very rare. In the visible region of the EM spectrum, the feature we describe as the colour of the object is the visible light that is not absorbed by that object. In the case of a green leaf, for example, the blue and red wavelengths are absorbed by the leaf, while the green wavelength is reflected and detected by our eyes.
In remote sensing, a detector measures the **electromagnetic (EM) radiation** that is reflected back from the Earth's surface materials. These measurements can help to distinguish the type of land covering. Soil, water and vegetation have clearly different patterns of reflectance and absorption over different wavelengths. The reflectance of radiation from one type of surface material, such as soil, varies over the range of wavelengths in the EM spectrum. This is known as the **spectral signature** of the material.

1.3 Sensors and platforms

A sensor is a device that measures and records electromagnetic energy. Sensors can be divided into two groups. **Passive sensors** depend on an external source of energy, usually the sun. The most common passive sensor is the photographic camera. **Active sensors** have their own source of energy; an example would be a radar gun. These sensors send out a signal and measure the amount reflected back. Active sensors are more controlled because they do not depend upon varying illumination conditions.



Passive sensors Active sensors

Fig. 2. Active and passive sensors

1.3.1 Orbits and swaths

The path followed by a satellite is referred to as its orbit. Satellites which view the same portion of the earth's surface at all times have geostationary orbits. Weather and communication satellites commonly have these types of orbits. Many satellites are designed to follow a north south orbit which, in conjunction with the earth's rotation (west-east), allows them to cover most of the earth's surface over a period of time. These are Near-polar orbits. Many of these satellites orbits are also Sun-synchronous such that they cover each area of the world at a constant local time of day. Near polar orbits also means that the satellite travels northward on one side of the earth and the southward on the second half of its orbit. These are called Ascending and Descending passes. As a satellite revolves around the earth, the sensor sees a certain portion of the earth's surface. The area imaged is referred to as the Swath. The surface directly below the satellite is called the Nadir point. Steerable sensors on satellites can view an area (off nadir) before and after the orbits passes over a target.

1.3.1.1 Satellite sensor characteristics

The basic functions of most satellite sensors are to collect information about the reflected radiation along a pathway, also known as the field of view (FOV), as the satellite orbits the Earth. The smallest area of ground that is sampled is called the instantaneous field of view (IFOV). The IFOV is also described as the pixel size of the sensor. This sampling or measurement occurs in one or many spectral bands of the EM spectrum. The data collected by each satellite sensor can be described in terms of spatial, spectral and temporal resolution.

1.3.1.2 Spatial resolution

The spatial resolution (also known as ground resolution) is the ground area imaged for the instantaneous field of view (IFOV) of the sensing device. Spatial resolution may also be described as the ground surface area that forms one pixel in the satellite image. The IFOV or ground resolution of the Landsat Thematic Mapper (TM) sensor, for example, is 30 m. The ground resolution of weather satellite sensors is often larger than a square kilometre. There are satellites that collect data at less than one meter ground resolution but these are classified military satellites or very expensive commercial systems.

1.3.1.3 Temporal resolution

Temporal resolution is a measure of the repeat cycle or frequency with which a sensor revisits the same part of the Earth's surf ace. The frequency will vary from several times per day, for a typical weather satellite, to 8—20 times a year for a moderate ground resolution satellite, such as Landsat TM. The frequency characteristics will be determined by the design of the satellite sensor and its orbit pattern

1.3.1.4 Spectral resolution

The spectral resolution of a sensor system is the number and width of spectral bands in the sensing device. The simplest form of spectral resolution is a sensor with one band only, which senses visible light. An image from this sensor would be similar in appearance to a black and white photograph from an aircraft. A sensor with three spectral bands in the visible region of the EM spectrum would collect similar information to that of the human vision system. The Landsat TM sensor has seven spectral bands located in the visible and near to mid infrared parts of the spectrum.

A **panchromatic image** consists of only one band. It is usually displayed as a grey scale image, i.e. the displayed brightness of a particular pixel is proportional to the pixel digital number which is related to the intensity of solar radiation reflected by the targets in the

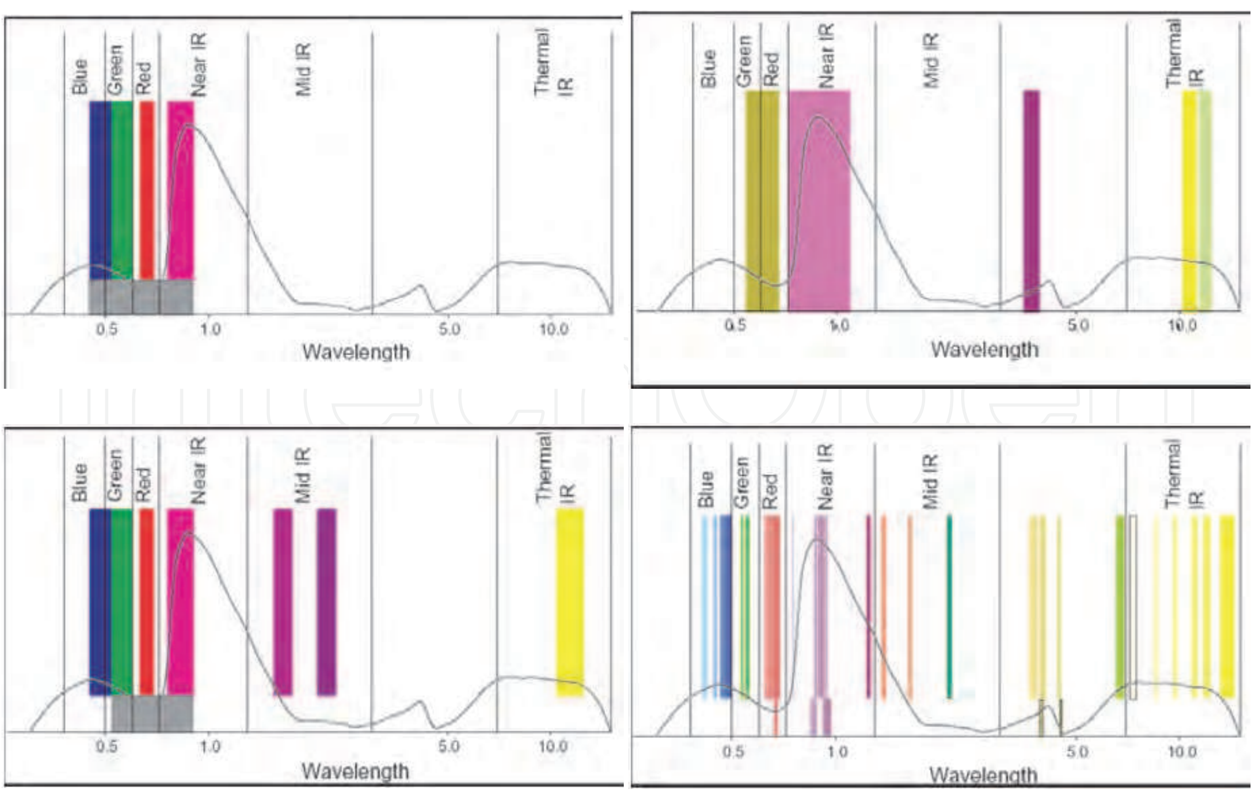


Fig. 3. Electromagnetic radiation spectrum with different resolution bands

pixel and detected by the detector. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area, though at a lower resolution.

Multispectral and hyperspectral images consist of several bands of data. For visual display, each band of the image may be displayed one band at a time as a **grey scale image**, or in combination of three bands at a time as a **color composite image**. Interpretation of a multispectral color composite image will require the knowledge of the **spectral reflectance signature** of the targets in the scene.

1.3.2 Platforms

Aerial photography has been used in agricultural and natural resource management for many years. These photographs can be black and white, colour, or colour infrared. Depending on the camera, lens, and flying height these images can have a variety of scales. Photographs can be used to determine spatial arrangement of fields, irrigation ditches, roads, and other features or they can be used to view individual features within a field.

Infrared images can detect stress in crops before it is visible with the naked eye. Healthy canopies reflect strongly in the infrared spectral range, whereas plants that are stressed will reflect a dull colour. These images can tell a farmer that there is a problem but does not tell him what is causing the problem. The stress might be from lack of water, insect damage, improper nutrition or soil problems, such as compaction, salinity or inefficient drainage. The farmer must assess the cause of the stress from other information. If the dull areas disappear on subsequent pictures, the stress could have been lack of water that was eased with irrigation. If the stress continues it could be a sign of insect infestation. The farmer still has to conduct in-field assessment to identify the causes of the problem. The development of cameras that measure reflectance in a wider range of wavelengths may lead to better quantify plant stress. The uses of these multi-spectral cameras are increasing and will become an important tool in precision agriculture.

Satellite remote sensing is becoming more readily available for use in precision agriculture. The **Landsat** and the **NOAA** polar-orbiting satellites carry instruments that can be used to determine crop types and conditions, and to measure crop acreage. The Advanced Very High Resolution Radiometer (AVHRR) carried onboard NOAA polar orbiting satellites measure reflectance from the earth's surface in the visible, near infrared, and thermal infrared portions of the electromagnetic spectrum.

This spectral sensitivity makes it suitable for measuring vegetative condition and because the satellite passes overhead twice a day, it can be used to detect rapidly changing conditions. Unfortunately, its use as a precision agriculture tool is limited because the spatial resolution of the sensor is nominally 1.1km. A possible application of this scanner would be to use the thermal infrared sensor to estimate daily maximum and minimum temperatures. These temperature estimates could then be used to determine degree-days that will drive pest development models.

Degree-day models are an essential part of IPM programs and the enhanced spatial coverage provided by satellites would allow for assessment of spatial variability in predicted events that is not possible with data from sparsely spaced weather stations currently used for these models. Remotely sensed data can also be used to determine irrigation scheduling and adequacy of irrigation systems for uniformly wetting an entire field. The sensors aboard the Landsat satellite measures reflected radiation in seven spectral bands from the visible through the thermal infrared. The sensors high spatial resolution (approximately 30m) makes it useful in precision agriculture. The spectral response and higher spatial resolution make it suitable for assessing vegetative condition for individual fields but the overpass frequency is only once every 16 days. The less frequent overpass makes it difficult to use these data for assessing rapidly changing events such as insect outbreaks or water stress. New satellites with enhanced capabilities are planned and remotely sensed data will become more widely used in management support systems.

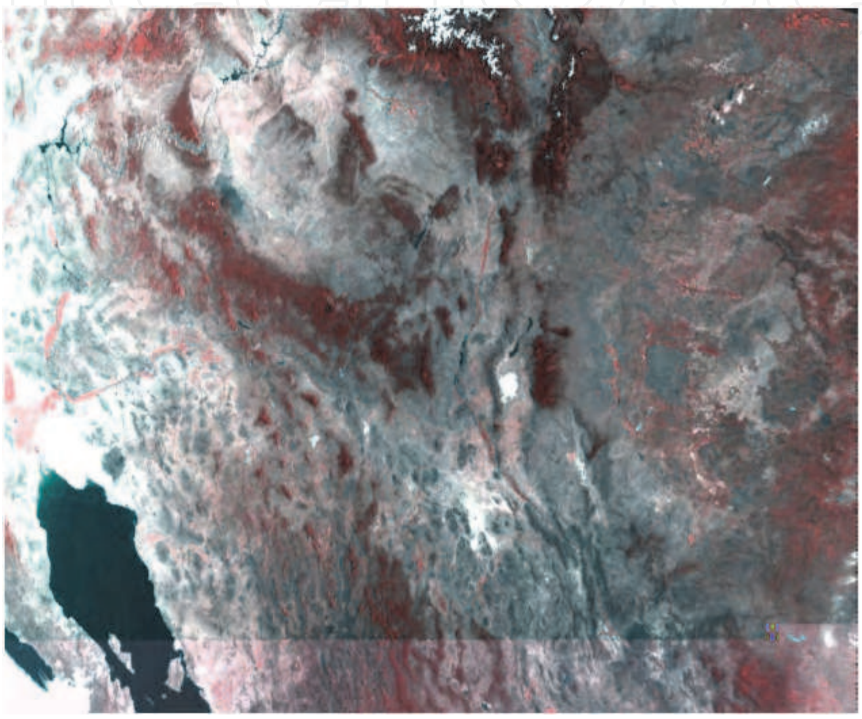


Fig. 4. Figure Advanced Very High Resolution Radiometer (AVHRR) image of the southwest Untied States. Image is centred on the Las Cruces, New Mexico.

1.3.3 Common satellites

1.3.3.1 GOES

5 spectral bands 1 - 41 km spatial resolution Geostationary

1.3.3.2 NOAA AVHRR

5 spectral bands 1.1 km spatial resolution 1 day repeat cycle

1.3.3.3 Landsat TM

7 spectral bands 30m spatial resolution 16 day repeat cycle

1.3.3.4 MODIS

Multi- spectral bands 250-1000m spatial resolution (band dependent) 1day repeat cycle

1.3.3.5 IKONOS

4 spectral Bands 4m spatial resolution 5 day repeat cycle

1.4 Spectral signatures of natural and human-made materials

Remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images.

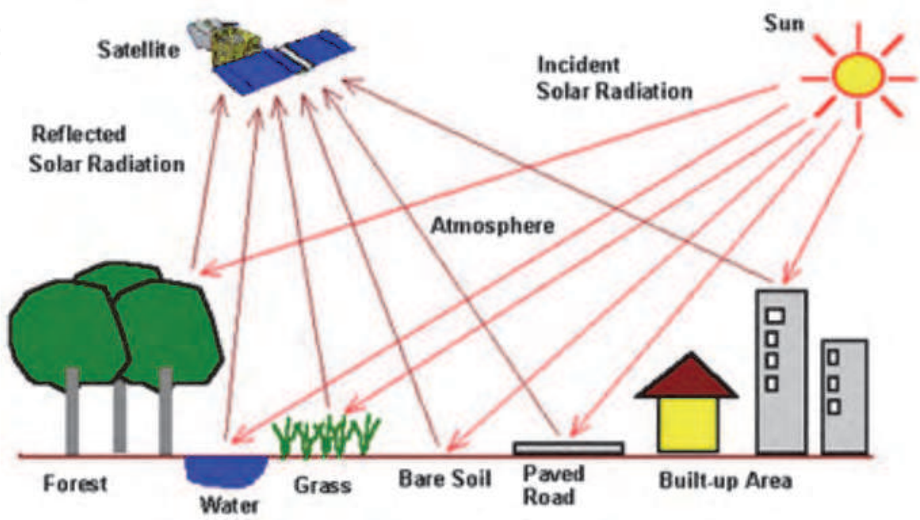


Fig. 5. Refraction and diffraction of radiations by different objects

1.5 Spectral reflectance signature

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a fun tion of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient **spectral resolution** to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing. The following graph shows the typical reflectance spectra of water, bare soil and two types of vegetation.

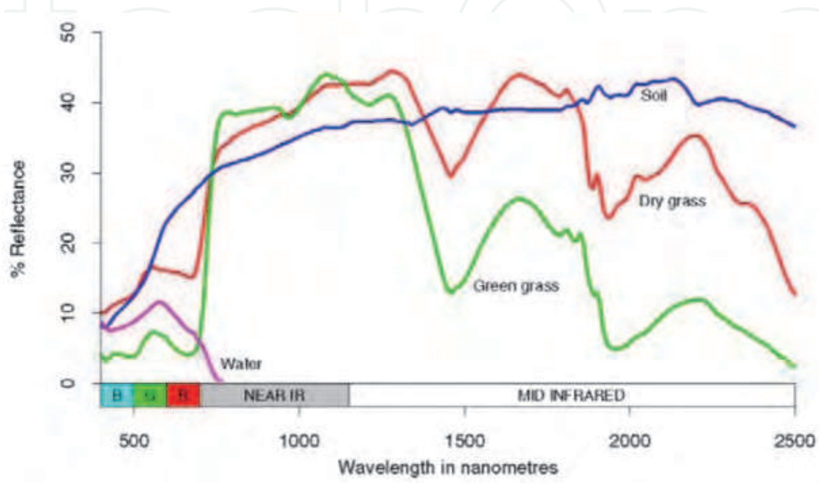


Fig. 6. Spectral resolution of different materials

The reflectance of clear water is generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, water appears dark bluish to the visible eye. Turbid water has some sediment suspension that increases the reflectance in the red end of the spectrum and would be brownish in appearance. The reflectance of bare soil generally depends on its composition. In the example shown, the reflectance increases monotonically with increasing wavelength. Hence, it should appear yellowish-red to the eye.

Vegetation has a unique spectral signature that enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectance. This property has been used in early reconnaissance missions during war times for "camouflage detection".

The shape of the reflectance spectrum can be used for identification of vegetation type. For example, the reflectance spectra of dry grass and green grass in the previous figures can be distinguished although they exhibit the generally characteristics of high NIR but low visible reflectance. Dry grass has higher reflectance in the visible region but lower reflectance in the NIR region. For the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants. These properties enable vegetation condition to be monitored using remotely sensed images.

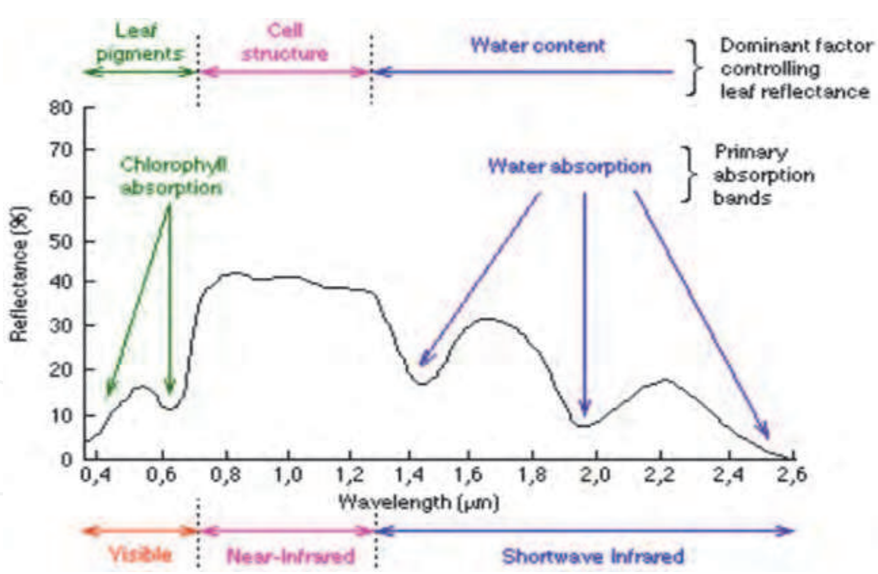


Fig. 7. Reflectance spectrum of different materials

1.6 Geodesy, geodetic datums and map projections

Geodesy is the branch of science concerned with the determination of the size and shape of the Earth. Geodesy involves the processing of survey measurements on the curved surface of the Earth, as well as the analysis of gravity measurements. Knowing the exact location of a pixel on the Earth's surface (its spatial location) is an essential component of remote sensing. It requires a detailed knowledge of the size and the shape of the Earth. The Earth is not a simple sphere. Topographic features such as mountain ranges and deep oceans disturb the surface of the Earth. The ideal reference model for the Earth's shape is one that can represent these irregularities and identify the position of features through a co-ordinate system. It should also be easy to use.

1.6.1 Flat Earth vs curved Earth

The "flat Earth" model is not appropriate when mapping larger areas. It does not take into account the curvature of the Earth. A "curved Earth" model more closely represents the shape of the Earth. A spheroid best represents the shape of the Earth because it is significantly wider at the equator than around the poles (Unlike a simple sphere). A spheroid, (also known as an ellipsoid) represents the equator as an elliptical shape, rather than a round circle. Surveying and navigation calculations can he performed over a large area when a spheroid is used as a curved Earth reference model.

1.6.2 Sea level and the composition of the Earth's interior

The surface of the sea is not uniform. The Earth's gravitational field shapes it. The rocks that make up the Earth's interior vary in density and distribution, causing anomalies in the gravitational field. These, in turn, cause irregularities in the sea surface. A mathematical model of the sea surface can be formulated; however, it is very complex and not useful for finding geographic positions on a spheroid reference model.

1.6.3 Types of geodetic datum

Based on these ideas, models can be established from which spatial position can be calculated. These models are known as geodetic datums and are normally classified into two types geocentric datum and local geodetic datum

A geocentric datum is one which best approximates the size and shape of the Earth as a whole. The center of its spheroid coincides with the Earth's center of mass. A geocentric datum does not seek to be a good approximation to any particular part of the Earth. **A local** geodetic datum is used to approximate the size and shape of the Earth's sea surface in a smaller area.

Datums and GIS

Having a standard accurate datum set becomes increasingly important as multiple layers of information about the same area are collected and analyzed. The layers are developed into geographic information systems (GIS), which enable the relationships between layers of data to be examined. In order to function effectively, a GIS must possess one essential attribute. It must have the ability to geographically relate data within and across layers. For example, if a dataset about vegetation is being examined against the data sets for topography and soils, the accurate spatial compatibility of the two datasets is critical.

1.6.4 Map projection coordinates

A map projection is a systematic representation of all or part of the Earth on a two dimensional surface, such as a flat sheet of paper. During this process some distortion of distances, directions, scale, and area is inevitable. There are several different types of map projections. No projection is free from all distortions, but each minimizes distortions in some of the above properties, at the expense of leaving errors in others. For example, the commonly used Transverse Mercator projection represents direction accurately, but distorts distance and area, especially those farthest from the equator. Greenland, for example, appears to be much larger than it really is. The Transverse Mercator projection is useful for navigation charts.

1.6.4.1 Universal Transverse Mercator (UTM)

Universal Transverse Mercator (UTM) is a global spatial system based on the Transverse Mercator projection. UTM divides the Earth into 60 equal zones, each being 6 degrees wide. Each zone is bounded by lines of longitude extending from the North Pole to the South Pole. Imagine an orange consisting of 60 segments. Each segment would be equivalent to a UTM zone. A rectangular grid coordinate system is used in most map projections. These coordinates are referred to as Eastings and Northings, being distances East and North of an origin. They are usually expressed in metres. Under the UTM system, each East and North coordinate pair could refer to one of sixty points on Earth — one point in each of the sixty zones. Because of this, the zone number needs to be quoted to ensure the correct point on Earth is being identified.

1.6.4.2 Global Positioning System

The Global Positioning System (GPS) is a satellite based system that gives real time three dimensional (3D) latitude, longitude, and height information at sub-meter accuracy. The system was developed by the United States military in the late 1970's to give troops accurate position and navigational information. A GPS receiver calculates its position on earth from radio signals broadcast by satellites orbiting the earth. There are currently twenty-four GPS satellites in this system. GPS equipment is capable of measuring a position to within centimetres but the accuracy suffers due to errors in the satellite signals. Errors in the signal can be caused by atmospheric interference, proximity of mountains, trees, or tall buildings. The government can also introduce errors in the signal for security purposes. This intentional degradation of the satellite signals is known as selective availability. The accuracy of the position information can be improved by using differential GPS. In differential GPS, one receiver is mounted in a stationary position, usually at the farm office, while the other is on the tractor or harvesting equipment. The stationary receiver calculates the error and transmits the necessary correction to the mobile receiver. GPS equipment suitable for precision agricultural cost several thousand dollars. Less expensive equipment is becoming available but the accuracy and capability is reduced.

1.6.4.3 Geographic Information System (GIS)

A Geographic Information System (GIS) is a computer-assisted system for handling spatial information. GIS software can be considered as a collection of software programs to acquire, store, analyze, and display information. The input data can be maps, charts, spreadsheets, or pictures. The GIS software can analyze these data using image processing and statistical procedures. Data can be grouped together and displayed as overlays. Overlays could be information such as soil type, topography, crop type, crop yield, pest levels, irrigation, and management information as shown.

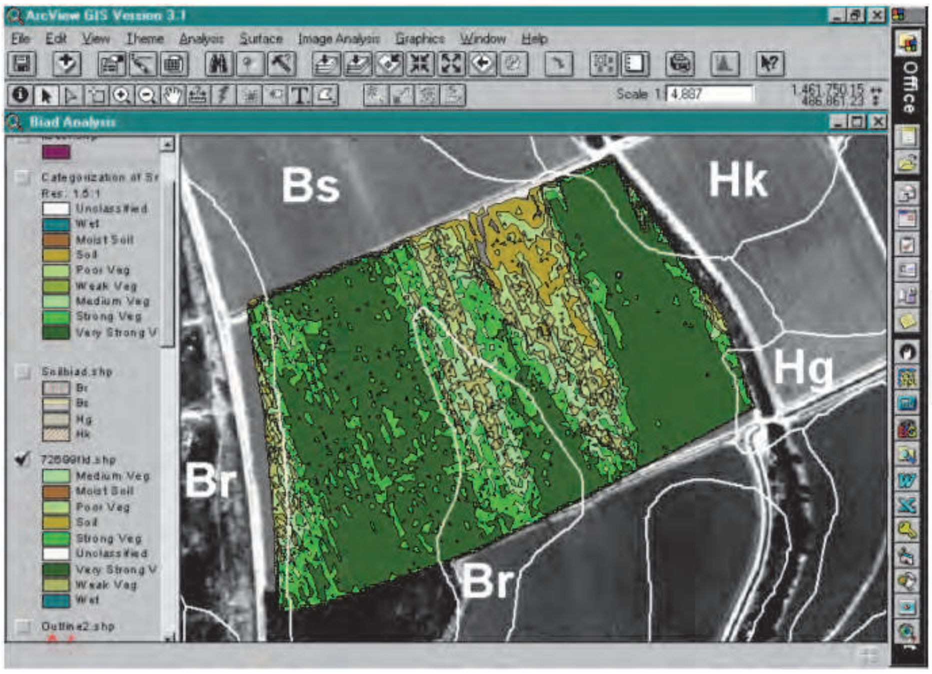


Fig. 8. Topographic GIS map of the forest area

Relationships can be examined and new data sets produced by combining a number of overlays. These data sets can be combined with models and decision support systems to construct a powerful management tool. For example, we could assess how far a field was from roads or non-agricultural crops. This information could be important in pest infestation or in planning chemical application. We could also examine crop yield relationship to soil type or other factors as show in the following figure. A number of GIS software packages are now commercially available. Spatial data for the GIS is often collected using GPS equipment but another source of spatial information is aerial and satellite imagery.

1.6.4.4 Pixels, images and colours

1.6.4.4.1 Colour composite images

In displaying a colour composite image, three primary colors (red, green and blue) are used when these three colours are combined in various proportions, they produce different colors in the visible spectrum. Associating each spectral band (not necessarily a visible band) to a separate primary colour results in a colour composite image.

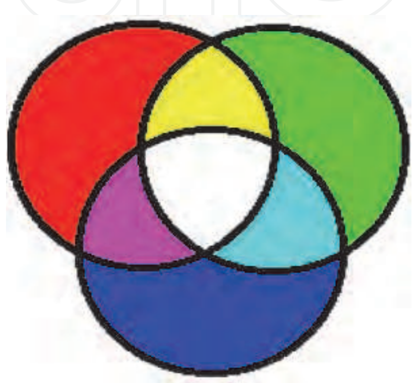


Fig. 9. Primary colour composite

Many colours can be formed by combining the three primary colours **(Red, Green, Blue)** in various proportions.

1.6.4.4.2 False colour composite

The display colour assignment for any band of a **multispectral image** can be done in an entirely arbitrary manner. In this case, the colour of a target in the displayed image does not have any resemblance to its actual colour. The resulting product is known as a **false color composite** image. There are many possible schemes of producing false color composite images. However, some scheme may be more suitable for detecting certain objects in the image.

1.6.4.4.3 Natural colour composite

When displaying a natural colour composite image, the spectral bands (some of which may not be in the visible region) are combined in such a way that the appearance of the displayed image resembles a visible colour photograph, i.e. vegetation in green, water in blue, soil in brown or grey, etc. Many people refer to this composite as a "**true colour**" composite. However, this term may be misleading since in many instances the colours are only simulated to look similar to the "true" colours of the targets. For example, the bands 3 (red band), 2 (green band) and 1 (blue band) of a **AVHRR** image can be assigned respectively to the R, G, and B colours for display. In this way, the colour of the resulting colour composite image resembles closely what the human eyes would observe.

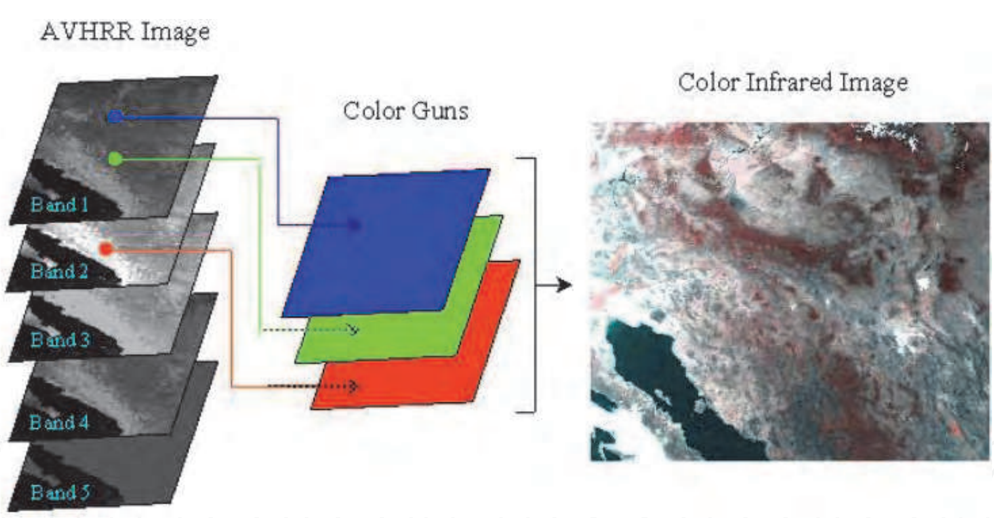


Fig. 10. Development of natural colour composite

1.7 Image processing and analysis

Many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. The choice of specific techniques or algorithms to use depends on the goals of each individual project. The key steps in processing remotely sensed data are **Digitizing of Images, Image Calibration, Geo-Registration,** and **Spectral Analysis.** Prior to data analysis, initial processing on the raw data is usually carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Depending on the user's requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include **radiometric correction** to correct for uneven sensor response over the whole image and **geometric correction** to correct for geometric distortion due to Earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if accurate geographical location of an area on the image needs to be known**, ground control points (GCP's)** are used to register the image to a precise map (**geo-referencing**).

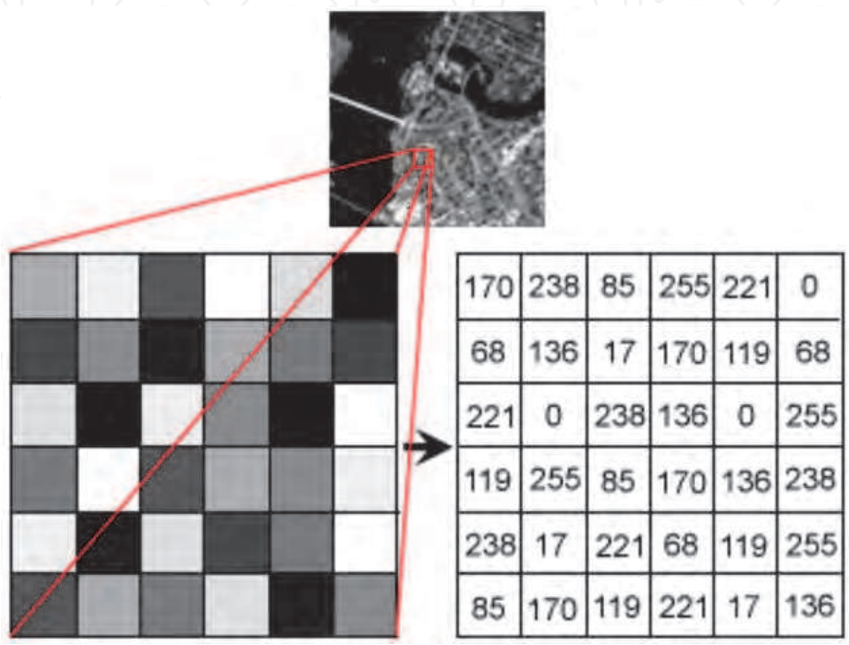


Fig. 11. Georeferencing of a map

1.7.1 Digitizing of images

Image digitization is the conversion of an analogue image, such as a photograph, into a series of grid cells. The value of each cell is related to the brightness, colour or reflectance at that point. A scanner is a simple way to digitize images. Many modern sensors now produce raw data in digital format.

1.7.2 Image enhancement

In order to aid visual interpretation, visual appearance of the objects in the image can be improved by **image enhancement** techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges. An example of an enhancement procedure is shown here.

1.7.3 Image classification

Different land cover types in an image can be discriminated using some **image classification** algorithms using spectral features, i.e. the brightness and "colour" information contained in each pixel. The classification procedures can be "supervised" or "unsupervised". In **supervised classification**, the spectral features of some areas of known land cover types are extracted from the image. These areas are known as the "**training areas**". Every pixel in the whole image is then classified as belonging to one of the classes depending on how close its spectral features are to the spectral features of the training areas. In **unsupervised classification**, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a landcover type by the analyst. Each class of land cover is referred to as a "**theme**" and the product of classification is known as a "**thematic map**". The information derived from remote sensing images are often combined with other auxiliary data to form the basis for a **Geographic Information System (GIS)**. A GIS is a database of different layers, where each layer contains information about a specific aspect of the same area which is used for analysis by the resource scientists.

1.8 Image interpretation

1.8.1 Vegetation indices

Different bands of a multispectral image may be combined to accentuate the vegetated areas.
One such combination is the ratio of the near-infrared band to the red band. This ratio is known as the Ratio Vegetation Index (RVI)

RVI = NIR/Red

Since vegetation has high NIR reflectance but low red reflectance, vegetated areas will have higher RVI values compared to non-vegetated aeras. Another commonly used vegetation index is the **Normalised Difference Vegetation Index (NDVI)** computed by

NDVI = (NIR - Red)/(NIR + Red)

Table shows equations and references for several indices that can be use in vegetation monitoring.

PARAMETER	EQUATION	REFERENCE
Normalized Difference Vegetation Index (NDVI)	(NIR-Red)/(NIR+Red)	Rouse *et al* (1974)
Water Band Index (WBI)	900/970 nm	Pefluelas *et al.* (1997)
Water Moisture Index (WMI)	1600/820 nm	Hunt and Rock (1989)
Photosynthesis Index	(531-570)/531+570)	Gamon *et al.* (1990)
Nitrogen Index (RN)	(550-600)/(800-(900)	Blackmer *et al.* (1996)
Chlorophyll based Difference Index (CI)	(850-710)/850-680)	Datt (1999)

Table 1. Equation and references for different parameters

Vegetation maps are produced by generating a normalized difference vegetation index from a infrared image and then doing a vegetation classification. Colour infrared photographs collect information in the green, red and near infrared light reflectance spectrum. Green vegetation reflects very strongly in the near infrared light range and therefore infrared images can detect stress in many crops before it is visible with the naked eye.
The Normalized Difference Vegetation Index (NDVI) is used to separate green vegetation from the background soil brightness. It is the difference between the near infrared and red reflectance normalized over the sum of these bands.

Fig. 12. Example of image processing of aerial infrared photographs to produce a vegetation map for a chile field.

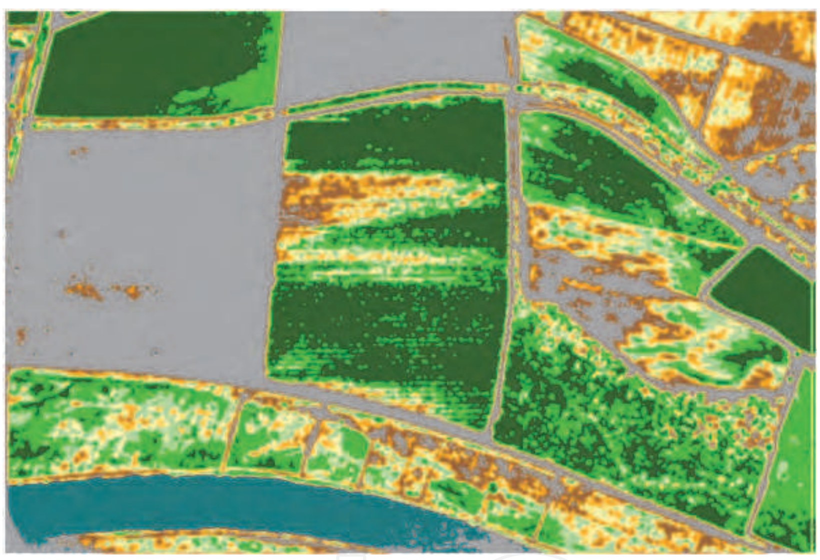


Fig. 13. Example of image processing of aerial infrared photographs to produce a vegetation map for a peddy field.

NDVI = (IR-Red)/(IR+Red)

These NDVI maps can then be classified into vegetation categories and displayed as a vegetation maps with different colours representing different levels of vegetation. In the map on the left browns and yellow represent bare soil and shades of green represent vegetation, darker greens are stronger vegetation.

1.9 Background on remote sensing

1.9.1 Remote sensing

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. As the term indicates, it applies to any information gathering device or method where the object of observation is remote from the device.

Out of a number of devices involved in remote sensing, the most common platforms are aircraft and satellites. The sensors associated with these devices are of two types, namely passive and active sensors. In a passive system, the instrument gathers information from the radiation that happens to arrive. The main sources of radiation for such systems are either solar radiation or thermal emissions. In the active system, it is the instrument itself on board the device that is the source of radiation. It sends signals to target under investigation, and receives the return signal, having the unique characteristics of the target features. As far as satellite remote sensing is concerned, systems operating in the visible and infrared part of the electromagnetic spectrum are passive while microwave instruments are either active or passive.

Currently, satellites are the main devices in remote sensing. And the two main types of satellites are the **Polar or Near-polar Orbiting** and **Geostationary** satellites. The Polar or Near Polar orbiting satellites are Sun-synchronous i.e. the satellites keep a precise pace with the Sun's westward progress as the earth rotates so that they always cross the equator at precisely the same solar time. Examples can be Landsat and NOAA satellites. Geostationary satellites are satellites which travel with an angular velocity that matches the earth's rotation. As a result, they remain at the same point above the earth at all times. An example is Meteosat. These satellites are helpful in obtaining constant and persistent image of a particular area at fixed interval which is a great advantage in monitoring a location with high temporal resolution to capture the transient behavior of objects such as rain clouds.

Estimation of biomass production will provide guidance to energy development polices including:

- The impact of improved stoves on fuel wood and dung energy consumption.
- The potential of increasing the supply of fuel wood through the establishment of small scale "forest plantations"
- The potential of dung and other fuels for biomass energy supply.

1.9.2 Principles involved

1.9.2.1 The photon and radiometric quantities

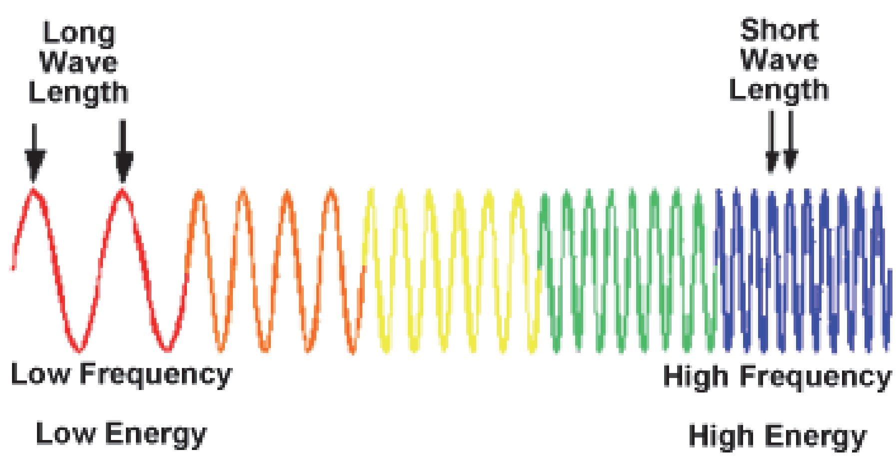
Most remote sensing texts begin by giving a survey of the main principles, to build a theoretical background, mainly in the physics of radiation. While it is important to have such a framework to pursue many aspects of remote sensing, we do not delve into this complex subject in much detail at this point. Instead, we offer on this and the next several pages an outline survey of the basics of relevant electromagnetic concepts. On this page, the nature of the photon is the prime topic. Photons of different energy values are distributed through what is called the Electromagnetic Spectrum.

Hereafter in this Introduction and in the Sections that follow, we limit the discussion and scenes examined to remote sensing products obtained almost exclusively by measurements within the Electromagnetic Spectrum (force field and acoustic remote sensing are briefly covered elsewhere in the Tutorial). Our emphasis is on pictures (photos) and images (either TV-like displays on screens or "photos" made from data initially acquired as electronic signals, rather than recorded directly on film). We concentrate mainly on images produced by sensors operating in the visible and near-IR segments of the electromagnetic spectrum but also inspect a fair number of images obtained by radar and thermal sensors.

The underlying basis for most remote sensing methods and systems is simply that of measuring the varying energy levels of a single entity, the fundamental unit in the electromagnetic (which may be abbreviated "EM") force field known as the *photon*. As you will see later on this page, variations in photon energies (expressed in Joules or ergs) are tied to the parameter *wavelength* or its inverse, *frequency*. EM radiation that varies from high to low energy levels comprises the *ElectroMagnetic spectrum* (EMS). Radiation from specific parts of the EM spectrum contain photons of different wavelengths whose energy levels fall within a discrete range of values. When any target material is excited by internal processes or by interaction with incoming EM radiation, it will emit or reflect photons of varying wavelengths whose radiometric quantities differ at different wavelengths in a way diagnostic of the material. Photon energy received at detectors is commonly stated in power units such as Watts per square meter per wavelength unit. The plot of variation of power with wavelength gives rise to a specific pattern or curve that is the *spectral signature* for the substance or feature being sensed.

Now, in more detail: The photon is the physical form of a quantum, the basic particle of energy studied in quantum mechanics (which deals with the physics of the very small, that is, particles and their behavior at atomic and subatomic levels). The photon is also described as the messenger particle for EM force or as the smallest bundle of light. This subatomic massless particle, which also does not carry an electric charge, comprises radiation *emitted* by matter when it is excited thermally, or by nuclear processes (fusion, fission), or by bombardment with other radiation (as well as by particle collisions). It also can become involved as *reflected* or *absorbed* radiation. Photons move at the speed of light: 299,792.46 km/sec (commonly rounded off to 300,000 km/sec or ~186,000 miles/sec).

Photon particles also move as waves and hence, have a "dual" nature. These waves follow a pattern that can be described in terms of a sine (trigonometric) function, as shown in two dimensions in the figure below.



(NOTE: Frequency refers to number of crests of waves of same wavelength that pass by a point in one second.)

Fig. 14. Movement of photon particles as sine waves

The distance between two adjacent peaks on a wave is its wavelength. The total number of peaks (top of the individual up-down curve) that pass by a reference lookpoint in a second is that wave's frequency (in units of cycles per second, whose SI version [SI stands for System International] is known as a Hertz [1 Hertz = 1/s^{-1}]).

A photon travels as an EM wave having two components, oscillating as sine waves mutually at right angles, one consisting of the varying electric field, the other the varying magnetic field. Both have the same amplitudes (strengths) which reach their maxima-minima at the same time. Unlike other wave types which require a carrier (e.g., water waves), photon waves can transmit through a vacuum (such as in space). When photons pass from one medium to another, e.g., air to glass, their wave pathways are bent (follow new directions) and thus experience *refraction*.

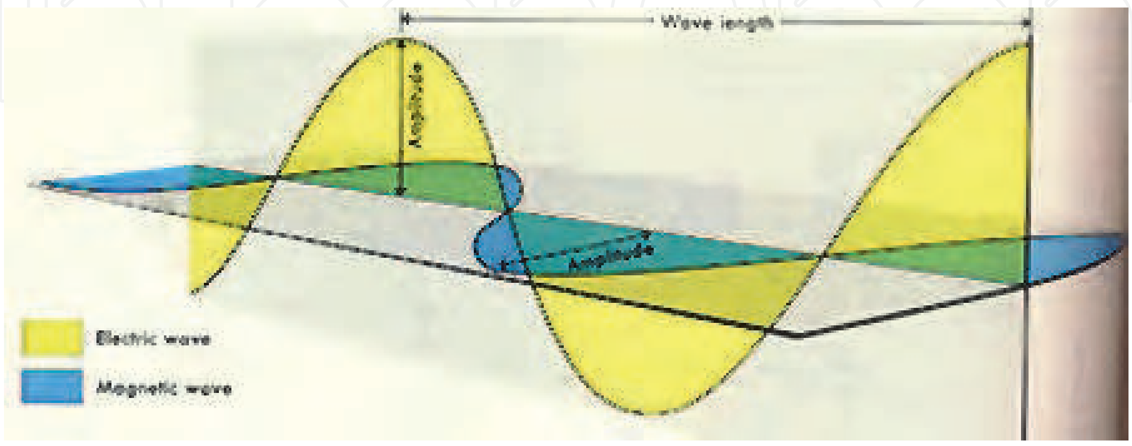


Fig. 15. Dual nature (electric and magnetic field) of photon particles

A photon is said to be quantized, in that any given one possesses a certain quantity of energy. Some other photon can have a different energy value. Photons as quanta thus show a wide range of discrete energies. The amount of energy characterizing a photon is determined using Planck's general equation:

$$E = hv$$

where h is Planck's constant (6.6260... x 10^{-34} Joules-sec)* and v is the Greek letter, nu, representing frequency (the letter "*f*" is sometimes used instead of v). Photons traveling at higher frequencies are therefore more energetic. If a material under excitation experiences a change in energy level from a higher level E_2 to a lower level E_1, we restate the above formula as:

$$\Delta E = E_2 - E_1 = hv$$

where v has some discrete value determined by (v_2 - v_1). In other words, a particular energy change is characterized by producing emitted radiation (photons) at a specific frequency v and a corresponding wavelength at a value dependent on the magnitude of the change.

1.9.3 Sources of electromagnetic (EM)- radiation

EM radiation is the energy resulting from the acceleration of electric charges and the associated electric and magnetic fields (this study is restricted to radiation emitted from the Sun and earth's surface). EM radiation is governed by the equations:

$$\Delta^2 E - \frac{\partial^2 E}{\partial t^2} = 0$$

$$\Delta^2 H - \frac{\partial^2 H}{\partial t^2} = 0$$

where the speed of light $c^2=1/(\mu\ \varepsilon)$

The energy associated with EM waves can be regarded as stream of photons travelling at speed of light, each photon having an energy hv, where h is Plank's constant and v is the frequency of the light. The EM spectrum, which is the range of wavelengths over which electromagnetic radiation extend, constitute of radio waves, micro waves, thermal infrared, infrared, visible, ultraviolet, x-ray, and gamma rays in decreasing order of wavelengths.

The ultimate source of energy for remote sensing is the Sun. Besides, all matter above absolute zero temperature emit radiation. Thus terrestrial objects are also sources of radiation, though it is considerably different in magnitude and spectral composition than that of the Sun. The emitted radiation from terrestrial objects is a function of temperature. From the principle of Black Body Radiation, the density of radiant energy U(v) emitted from a black body in the frequency range v+dv and v is:

$$U(v)d\nu = \frac{8\hbar}{C^3} \frac{v^3 dv}{\exp\left(\frac{\hbar v}{kT} - 1\right)}$$

which is the **Planck distribution law**. The total energy density overall frequencies is :

$$U = \int_o^\infty U(v)dv = \frac{8\pi^5 k^4}{15c^3 h^3} T^4 = aT^4$$

where **a** is a universal constant.

The intensity emitted from an object is therefore:

$$I = \varepsilon \sigma T^4$$

This is the **Stefan - Boltzman** Law

The spectral distribution of emitted energy varies with temperature as shown in **Figure 1**. Meanwhile, the wavelength at which greatest energy density occurs varies inversely with temperature and is given by Wein's displacement law:

$$\lambda_{\max} T = \frac{hc}{4.965K} = 2.898x10^{-3} m.k$$

1.9.4 Energy interaction in the atmosphere

Atmosphere can have a profound effect on the intensity and spectral composition available to any sensing system as the radiation which reaches the sensed object passes through a certain optical path length of atmospheric air. These effects are caused principally through the mechanism of atmospheric **scattering** and **absorption**.

1.9.4.1 Scattering

As stated above, the atmosphere can have a significant effect on the incoming and outgoing radiation by scattering. There are three types of scattering depending on the size of particle involved. And these are **Rayleigh scattering**, **Mie scattering** and **Non-selective**

scattering where Rayleigh and Non-selective scattering are the limiting cases of Mie scattering.
For Rayleigh scattering to occur, the particle size must not be larger than about 1/10th of the wavelength of the light. In a gas with N molecules per unit volume and refractive index n, the Rayleigh extinction coefficient α for a wavelength is approximately:

$$\alpha \approx \frac{32\pi^3}{3N\dagger}(n-1)^2$$

Rayleigh Sc atter i $\propto \frac{1}{\dagger}$

The extinction coefficient decreases as a wavelength increases. Specifically, the amount of scattering is inversely proportional to the fourth power of wavelength.
Mie scatter occurs for particles whose diameter is approximately equal to the wavelength. In a gas containing N spherical particles of radius R, the effective cross-section is given by:

σ = NAds Ŗ†

where **Ads** - is the volume in which the gas is contained, provided that no one particle lies in the shadow of another particle. If no absorption takes place, the extinction coefficient equals to scattering extinction co-efficient. Mie extinction coefficient is given by

$$\alpha = NK\pi R^2$$

where **K** = the extinction factor
The ratio of scattered to incident light can be expressed as:

$$\frac{i}{I_o} = -\alpha ds$$

In this type of scattering, as the particles are of the order of wavelength, the light scattered from one part of the surface can be out of phase with coming from another part, unlike Rayleigh scattering were there is no phase difference between the light source and the scattered light. For Mie scattering, phase difference will be small for small scattering angle which gives rise to a large intensity in the forward direction and less in the reverse.
Non-selective scattering occurs when the diameter of the scattering particles is much larger than the wavelength. Water droplets, for example, cause such a scattering. They commonly have diameter in the range 5 to 100m and scatter all visible wavelengths, equal quantities of blue, green, and red light are scattered, making fog and clouds appear white.

1.9.4.2 Absorption

When light pass through a certain optical path in the atmosphere, it experiences absorption in addition to scattering by the existing particles. The intensity of the light diminishes according
To the equation :

$$I = I_o \exp(-\alpha^1)$$

where α is the absorption coefficient

In the atmosphere, the most efficient absorbers of radiation are water vapour, carbon dioxide, and ozone.

The effect of this absorption is to leave only few regions known as atmospheric windows, in which the atmosphere transmits a substantial proportion of electromagnetic radiation. These are the only regions that can be used in remote sensing of the earth's surface.

Both scattering and absorption increase with increase in path length or with an increase in air mass.

1.9.5 Energy interaction with the earth's surface

When a light wave is incident on a surface, it will be reflected, transmitted, or absorbed. Furthermore, the energy of the absorbed radiation can be re-emitted as other forms of radiation. For an incident wave of intensity $\mathbf{I_o}$ the intensity of the reflected wave is $\mathbf{rI_o}$ and the amplitude of the rest is $\mathbf{(1 - r)I_o}$, where **r** is the coefficient of reflection.

When EM radiation is incident on a given surface feature, out of the three fundamental processes the reflected part is often of interest in remote sensing. (thermal emission are also often of interest). The reflected part $\mathbf{(rI_o)}$ will be different for different earth features depending on the type of material and the condition of the material (e.g. dry or wet). Reflectivity is also dependent on the wavelength or frequency of the incoming radiation. The function which describes the dependence of reflectivity on wavelength is called the spectral reflectance function, and is given by:

$$\rho_2 = \frac{Energy\ of\ reflected}{Energy\ of\ incident}$$

Different objects have very distinct spectral reflectance curves. It is the differences in spectral reflectance that allows one to distinguish different materials and objects using remotely sensed reflected radiation.

For thermal infrared wavelengths, the reflected radiation is outweighed by the emitted energy of the surface features. Hence in the thermal infrared, the radiation received from an object depends on its emissivity and temperature. Meanwhile, the temperature of an object will depend on its absorptivity (how much radiation it absorbs), its thermal conductivity (rate at which heat pass through a material), thermal capacity (ability of a material to store heat), and thermal inertia (thermal response of material to temperature change). Since our investigation focuses on non-thermal images, we will not discuss thermal remote sensing methods in detail.

1.9.6 Data acquisition and interpretation

Detection of EM energy can be performed either photographically or electronically. The process of photography uses chemical reactions on the surface of a light sensitive film to detect energy variation within a scene while electronic sensors generate in electrical signals that corresponds to the energy or intensity of the detected radiation. The advantage of visual (photographic) is that it is simple, it provides high good spatial detail (because of the high resolution of chemical films) and geometric integrity (geometry is not distorted). On the other hand, electronics have the advantage of broader spectral sensitivity and easier conversion of the image to digital form.

Photographic images are interpreted visually (or scanned to convert them into digital images) whereas electronic images are interpreted digitally. The electronic image constitutes an array of pixels which vary in the level of brightness in accordance with the radiation received from the surface feature they represent. Pixel brightness is converted to a binary number. In our case pixel values are 8-bit binary numbers representing integer values from 0 to 255. These are positive integers that result from quantizing of the original electrical signal from the sensor.

1.10 Remote sensing of biomass production

1.10.1 Reflectance characteristics of green plants

Green plants have a unique spectral reflectance curve. In the visible part of the spectrum, plants strongly absorb light in the blue (0.45μ m) and red (0.67nm) regions and reflect strongly in the green portion of the spectrum due to the presence of chlorophyll. In cases where the plant is subjected to stress or to a condition which hinders growth, the chlorophyll production will decrease. And this in turn leads to less absorption in the blue and red bands.
In the near infrared portion of the spectrum (0.7 - 1.3μm), green plant reflectance increases to 40 - 50% of incident light. Beyond 1.3μm, there are dips in the reflectance curve due to absorption by water in the leaves.

1.10.2 Principles of detection

The differential reflection of green plants in the visible and infrared portion of the spectrum makes possible the detection of green plants from satellites. Other features on the earth surface don't have such a unique step-like character in the 0.65 - 0.75μm range of the reflectance curve. NDVI is commonly used to represent this character. It is calculated from Advanced Very High Resolution Radiometer (AVHRR) data from NOAA-8 and NOAA-9 polar orbiting satellite and is defined as:

$$NDVI = \frac{CHN2 - CHN1}{CHN2 + CHN1}$$

where **CHN1** and **CHN2** are reflectance in the visible (red) (0.58 - 0.68 μm) and near infrared channels (0.725 - 1.10 μm) respectively. NDVI is determined by the degree of absorption by chlorophyll in the red wavelengths, which is proportional to green leaf density. Therefore, NDVI correlates well with green leaf biomass, leaf area index, and other related parameters.

1.10.3 Estimation of radiation use efficiency in plants

Plants make use of specific energy wavelengths (0.4 - 0.7 μm) for the process of photosynthesis. The photo-synthetically active radiation constitutes about 50% of the energy that is emitted from the sun. Out of this phot-synthetically active radiation (PAR), about 80% of the radiation incident on a plant leaf is captured by photo-synthetically active compounds. The rest is lost by reflection and absorption by non-photosynthesizing materials. A minimum of eight photons are required to produce a glucose from a single carbon-dioxide and glucose stores 28% of the captured energy in the form of chemical energy of the molecules. And finally, as the plant produces the glucose molecule it will use about 40% of the converted energy for dark respiration. Therefore, the maximum photosynthetic efficiency is:

$$100 \times 0.50 \times 0.80 \times 0.28 \times 0.60 = 6.70$$

This result applies to c_4 plants (so-called because their first product of photosynthesis is 4-carbon sugar). For c_3 plants, like wheat and rice, the efficiency is lower due to photo-respiration effects.

1.11 Remote sensing of radiation intensity

1.11.1 Solar constant

The average solar irradiance received outside the earth atmosphere is called Solar Constant. The intensity of solar radiation above the earth's atmosphere has nearly constant value unlike irradiance received at the ground. It's average value is 1367 W/m² though it shows some variation due to variations in solar activity. Annual fluctuations due to Earth-Sun distance give rise to a variation of ±3.4% of the extra-terrestrial irradiance and are given by

$$E_o = \langle E_0 \rangle (1 + 0.0167\cos((2/365)*(D-3)))^2$$

where $\langle E_0 \rangle$ is the mean value of solar constant, **D** is the Julian days.

1.11.2 Radiation reflected and received by the ground

Radiation received at the ground surface is a combination of direct radiation, which comes from the sun after passing through a path length in the transparent atmosphere, and diffuse radiation which is radiation reflected by clouds and scattered by atmosphere in general. The contribution of diffuse radiation to irradiance received by ground depends on the atmospheric thickness, moisture content, cloud frequency, turbidity of the atmosphere, and angle of zenith.

The radiation that is reflected from the ground is very small compared to that reflected from the clouds. Its value depends on the reflectance of different earth surface features. In many cases, surface albedo is taken to be uniform (0.15) across the land.

1.11.3 Atmospheric effects

Atmosphere plays a major role at attenuation and reflection of light that pass through it. Their main effects are reflection, absorption, and scattering, depending on the wavelength and air mass ratio.

1.11.4 Air mass ratio

Air mass ratio is defined as the ratio of the path length of the radiation through the atmosphere at a given angle of a reference path length. The reference path length is that obtained by light traveling to a point at sea level straight through the atmosphere (vertically). The air mass ratio depends on the angle of zenith and the height above sea level of the observer. For small angles, the ratio is expressed as;

$$m = \sec \theta_z$$

where θ_z is the zenith angle. As the angle of zenith increases, the air mass ratio increases i.e., the attenuation increases.

1.11.5 Atmospheric absorption and reflection

Light passing through the atmosphere experiences absorption, scattering and reflection. Absorption causes heating and eventual re-emission of the absorbed energy as long wavelength radiation. Scattering is a wavelength dependent change in a direction. On the average 30% extra-terrestrial irradiance is reflected to outer space mainly due to cloud.

1.11.6 Irradiance variation

Irradiance received at a given location may differ in magnitude from hour to hour, day to day, month to month, and season to season depending on air mass, turbidity, moisture content, cloud frequency, and angle of zenith. The seasonal variation give rise to a significant amount of fluctuations in the irradiance received. This fluctuation in irradiance is due to variation in the declination angle from season to season. The declination angle **(δ)** that the earth posses with respect to the sun varies from season to season. In the middle of march and september the declination angle, **δ** , is zero (0^o), where as $\delta = 23.5^o$ and $\delta = -23.5^o$ in the middle of June and December respectively. Analytically, the declination angle is expressed as :

$$\delta = 23.5^o \sin\left(360\frac{(284+D)}{365}\right)$$

where **D** is the Julian days.

Depending on the latitude, for a given declination angle, the irradiance increases or decreases. Moreover, irradiance varies with latitude. Irradiance variation due to seasonal variation is great at high latitudes. Variation in the earth sun distance also contributes to the variation in irradiance received although its contribution is very small.

2. Applications

2.1 Forestry applications

Satellite imagery is used to identify and map: -

- The species of native and exotic forest trees.
- The effects of major diseases or adverse change in environmental conditions.
- The geographic extent of forests.

This application of satellite imagery has led to the extensive use of imagery by organizations that have an interest in a range of environmental management responsibilities at a state and national level.

2.1.1 Greenhouse gases — sinks and sources

Forests are often referred to as *carbon sinks.* This description is used because during photosynthesis, carbon dioxide, the major greenhouse gas, is taken from the atmosphere and converted into plant matter and oxygen.

Climate change has serious implications for Malaysia and overseas countries alike. Sustainable v land management is essential for effective greenhouse gas management; hence, it is important to acquire data on land cover in Malaysia. Remotely sensed land cover changes are used in calculations of our national emission levels, and data collected on a national scale will enable governments to develop responses to land clearing.

2.1.2 Vegetation health

Vegetation can become stressed or less healthy because of a change in a range of environmental factors. These factors include lack of water, concentration of toxic elements/herbicides and infestation by insects/viruses. The spectral reflectance of vegetation changes according to the structure and health of a plant. In particular, the influence of chlorophyll in the leaf pigments controls the response of vegetation to radiation in the visible wavelength. As a plant becomes diseased, the cell structure of a plant alters and the spectral signature of a plant or plant community will change. The maximum reflection of electromagnetic radiation from vegetation occurs in the near infrared wavelengths. Vegetation has characteristically high near-infrared reflectance and low red reflectance. Air-borne scanners using narrow spectral bands between 0.4 urn and 0.9 urn can indicate deteriorating plant health before a change in condition is visible in the plant itself.

2.1.3 Biodiversity

Vegetation type and extent derived from satellite imagery can be combined, with biological and topographic information to provide information about biodiversity. Typically, this analysis is done with a geographic information system.

2.1.4 Change detection

Satellite imagery is not always able to provide exact details about the species or age of vegetation. However, the imagery provides a very good means of measuring significant change in vegetation cover, whether it is through clearing, wildfire damage or environmental stress. The most common form of environmental stress is water deficiency.

2.2 Geology

Remote sensing is useful for providing information relevant to the geosciences. For example, remote sensing data are used in:

- Mineral and petroleum exploration,
- Mapping geomorphology, and
- Monitoring volcanoes.

2.3 Land degradation

Imagery can be used to map areas of poor or no vegetation cover. A range of factors, including saline or sodic soils, and overgrazing, can cause degraded landscapes.

2.4 Oceanography

Remote sensing is applied to oceanography studies. Remote sensing is used, for example, to measure sea surface temperature and to monitor marine habitats.

2.5 Meteorology

Remote sensing is an effective method for mapping cloud type and extent, and cloud top temperature. In many of the applications identified above remotely sensed data are used with a range of other Earth science data to provide information about the natural environment. This analysis of Earth science data from a range of sources is usually done in a geographic information system (GIS).

2.6 Applications in agriculture, forestry, and ecology

2.6.1 General principles for recognizing vegetation

Planet Earth is distinguished from other Solar System planets by two major categories: Oceans and Land Vegetation. The oceans cover ~70% of the Earth's surface; land comprises 30%. On the land itself, the first order categories break down as follows: Trees = 30%; Grasses = 30%; Snow and Ice = 15%; Bare Rock = 18%; Sand and Desert Rock = 7%. We have already seen in previous Sections and in the Overview that in false colour imagery the remote sensing signature of vegetation is a bright red. The landscape shown in this first image could almost be on Mars except for the presence of this bright red sign of vegetation. This is the Ouargla Oasis in the Sahara Desert of southern Algeria, a concentration of trees and plants where groundwater reaches the surface:

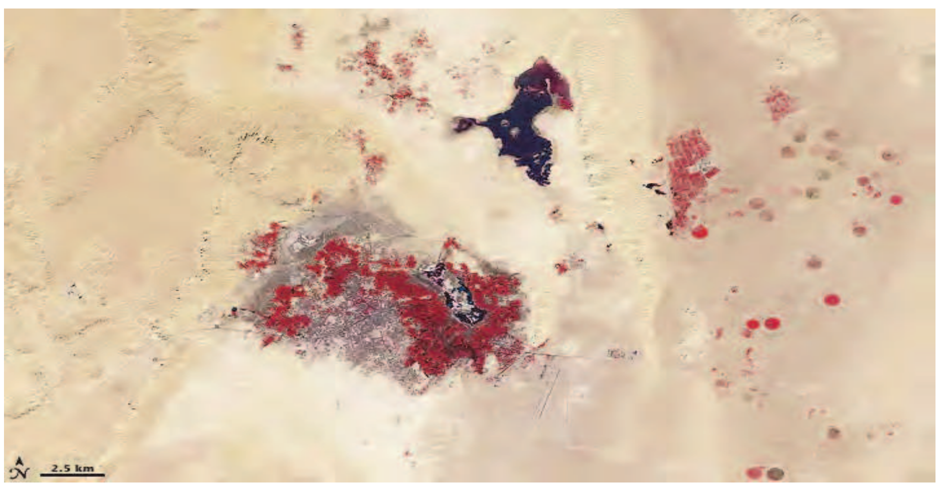


Fig. 16. Image of the Ouargla Oasis in the Sahara Desert of southern Algeria

On Earth, the amount of vegetation within the seas is huge and important in the food chain. But for people the land provides most of the vegetation within the human diet. The primary categories of land vegetation (biomes) and their proportions is shown in this pie chart:

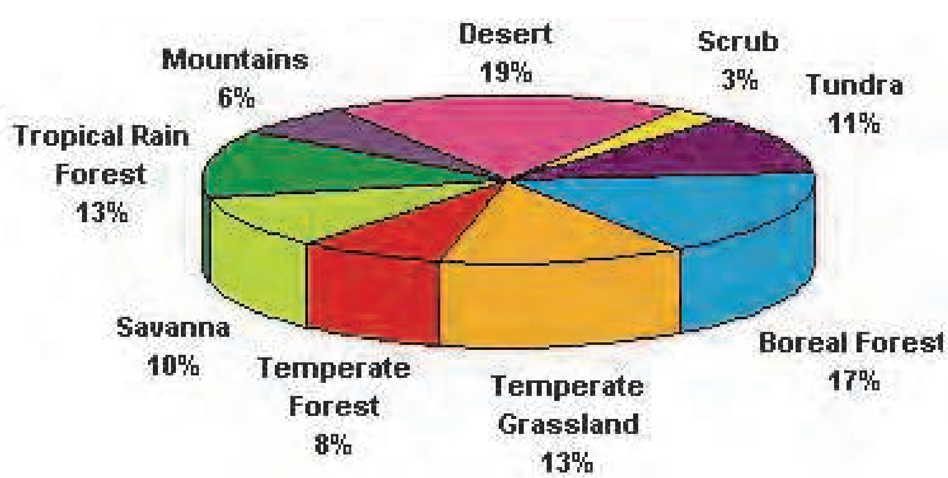


Fig. 17. Pie chart for land vegetation (biomes) and their proportions

These biomes are defined in part by the temperature and precipitation controls that differentiate them:

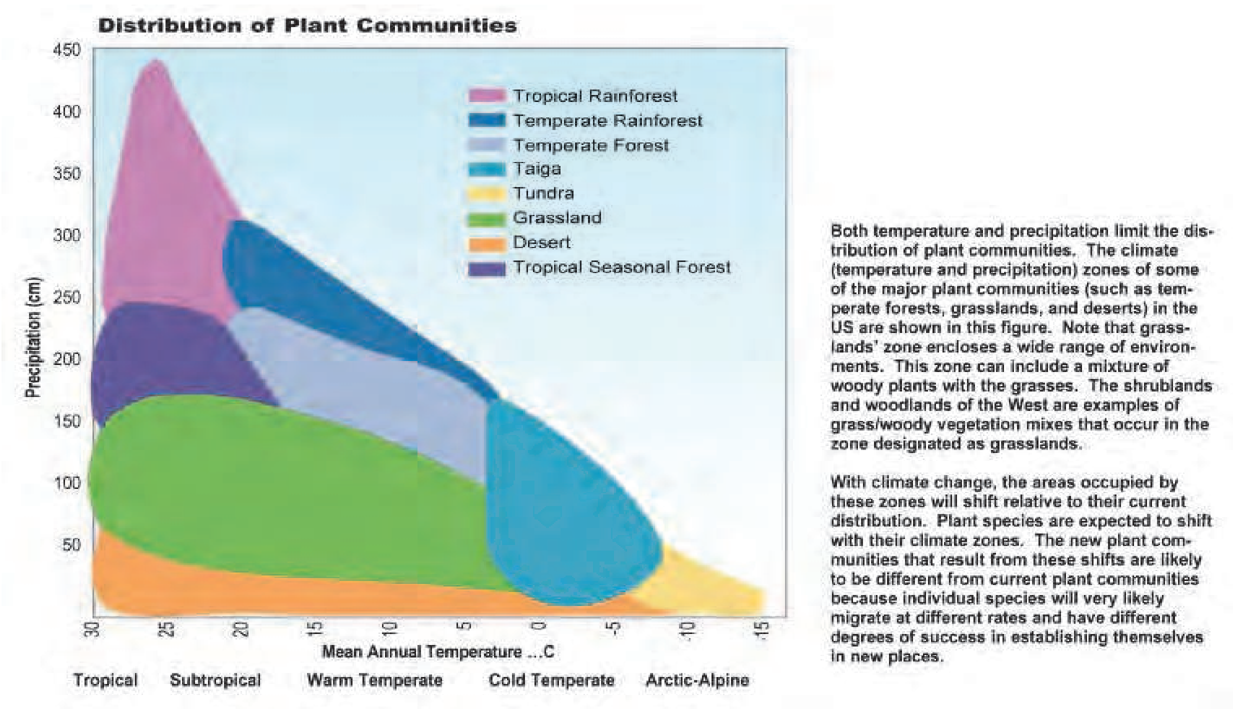


Fig. 18. Distribution of land vegetation by temperature and precipitation controls

Global maps of vegetation biomes on the continents show this general distribution:

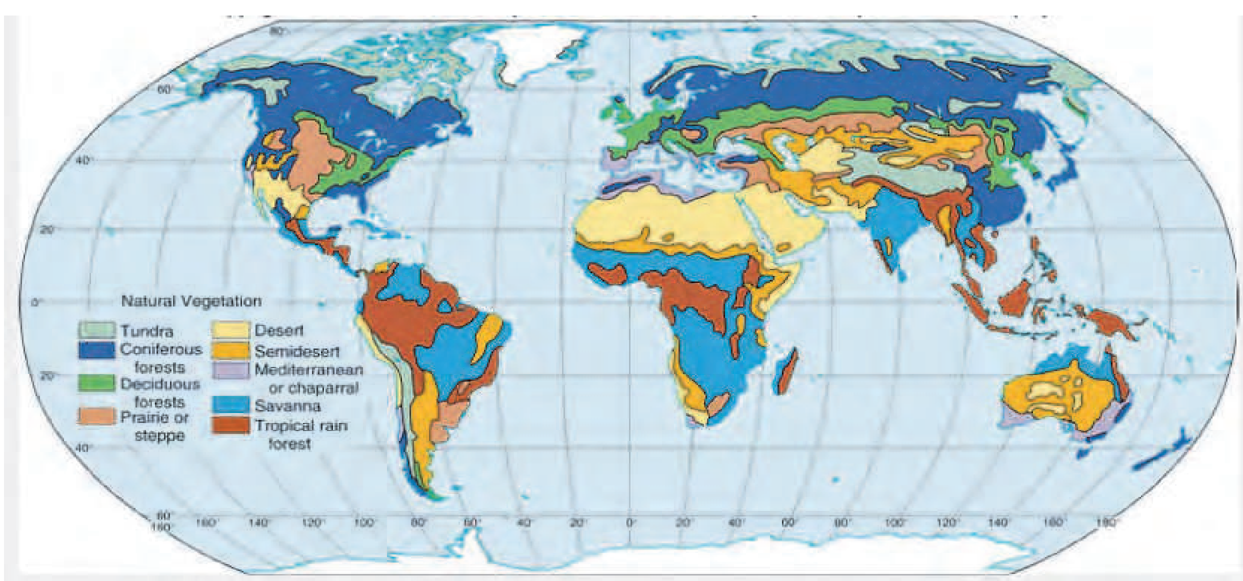


Fig. 19. Global maps of land vegetation (biomes)

A fair number of global vegetation maps have been published. These usually show slight to moderate differences, depending in part with the types and numbers of classes established in the classification. There also exists a notable correlation between vegetation classes and climate. Remote sensing has proven a powerful "tool" for assessing the identity, characteristics, and growth potential of most kinds of vegetative matter at several levels (from biomes to individual plants). Vegetation behaviour depends on the nature of the vegetation itself, its interactions with solar radiation and other climate factors, and the availability of chemical nutrients and water within the host medium (usually soil, or water in marine environments). A common measure of the status of a given plant, such as a crop used for human consumption, is its potential productivity (one such parameter has units of bushels/acre or tons/hectare, or similar units). Productivity is sensitive to amounts of incoming solar radiation and precipitation (both influence the regional climate), soil chemistry, water retention factors, and plant type. Examine the diagram below to see how these interact, keeping in mind that various remote sensing systems (e.g., meteorological or earth-observing satellites) can provide inputs to productivity estimation:

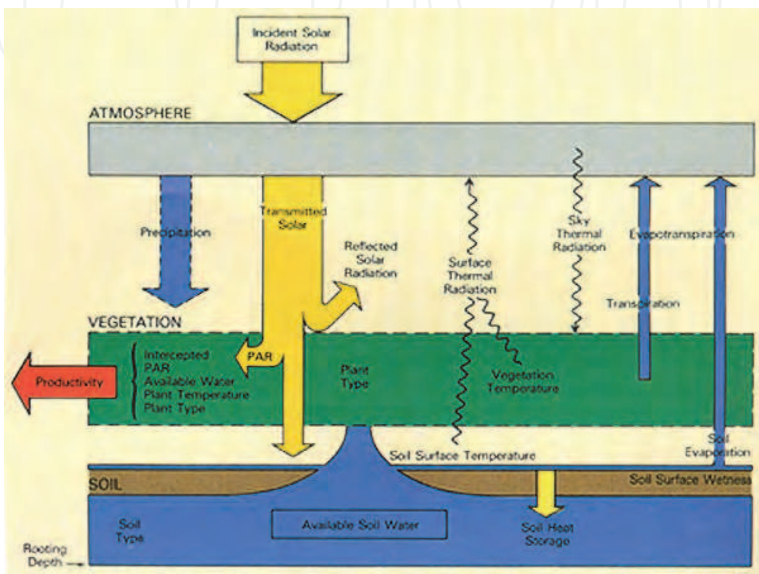


Fig. 20. Interaction between productivity and solar radiations

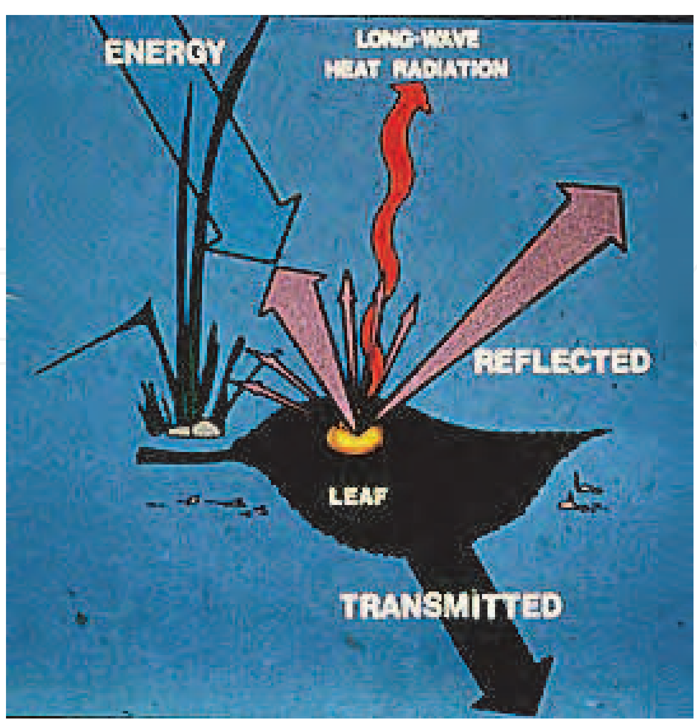


Fig. 21. Reflection and absorption of radiations through biomass

Because many remote sensing devices operate in the green, red, and near infrared regions of the electromagnetic spectrum, they can discriminate radiation absorption and reflectance properties of vegetation. One special characteristic of vegetation is that leaves, a common manifestation, are partly transparent allowing some of the radiation to pass through (often reaching the ground, which reflects its own signature). The general behaviour of incoming and outgoing radiation that an act on a leaf is shown in figure 21.

Now, consider this diagram which traces the influence of green leafy material on incoming and reflected radiation.

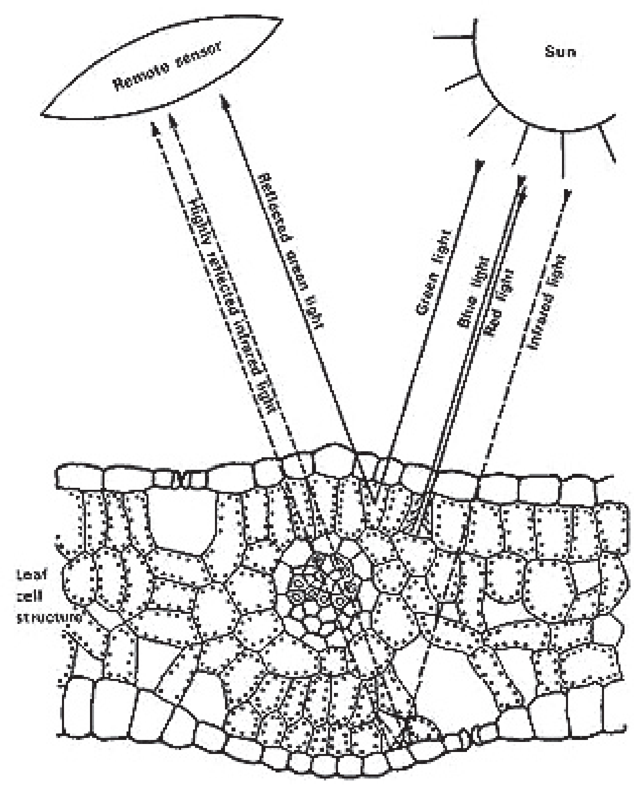


Fig. 22. The influence of green leafy material on incoming and reflected radiation.

Absorption centred at about 0.65 µm (visible red) is controlled by chlorophyll pigment in green-leaf chloroplasts that reside in the outer or Palisade leaf. Absorption occurs to a similar extent in the blue. With these colours thus removed from white light, the predominant but diminished reflectance of visible wavelengths is concentrated in the green. Thus, most vegetation has a green-leafy colour. There is also strong reflectance between 0.7 and 1.0 µm (near IR) in the spongy mesophyll cells located in the interior or back of a leaf, within which light reflects mainly at cell wall/air space interfaces, much of which emerges as strong reflection rays. The intensity of this reflectance is commonly greater (higher percentage) than from most inorganic materials, so vegetation appears bright in the near-IR wavelengths (which, fortunately, is beyond the response of mammalian eyes). These properties of vegetation account for their tonal signatures on multispectral images: darker tones in the blue and, especially red, bands, somewhat lighter in the green band, and notably light in the near-IR bands (maximum in Landsat's Multispectral Scanner Bands 6 and 7 and Thematic Mapper Band 4 and SPOT's Band 3).

Identifying vegetation in remote-sensing images depends on several plant characteristics. For instance, in general, deciduous leaves tend to be more reflective than evergreen needles. Thus, in infrared colour composites, the red colours associated with those bands in the 0.7 - 1.1 µm interval are normally richer in hue and brighter from tree leaves than from pine needles.

These spectral variations facilitate fairly precise detecting, identifying and monitoring of vegetation on land surfaces and, in some instances, within the oceans and other water bodies. Thus, we can continually assess changes in forests, grasslands and range, shrub lands, crops and orchards, and marine plankton, often at quantitative levels. Because vegetation is the dominant component in most ecosystems, we can use remote sensing from air and space to routinely gather valuable information helpful in characterizing and managing of these organic systems.

This discrimination capability implies that one of the most successful applications of multispectral space imagery is monitoring the state of the world's agricultural production. This application includes identifying and differentiating most of the major crop types: wheat, barley, millet, oats, corn, soybeans, rice, and others. This capability was convincingly demonstrated by an early ERTS-1 classification of several crop types being grown in Holt County, Nebraska. This pair of image subsets, obtained just weeks after launch, indicates what crops were successfully differentiated; the lower image shows the improvement in distinguishing these types by using data from two different dates of image acquisition:

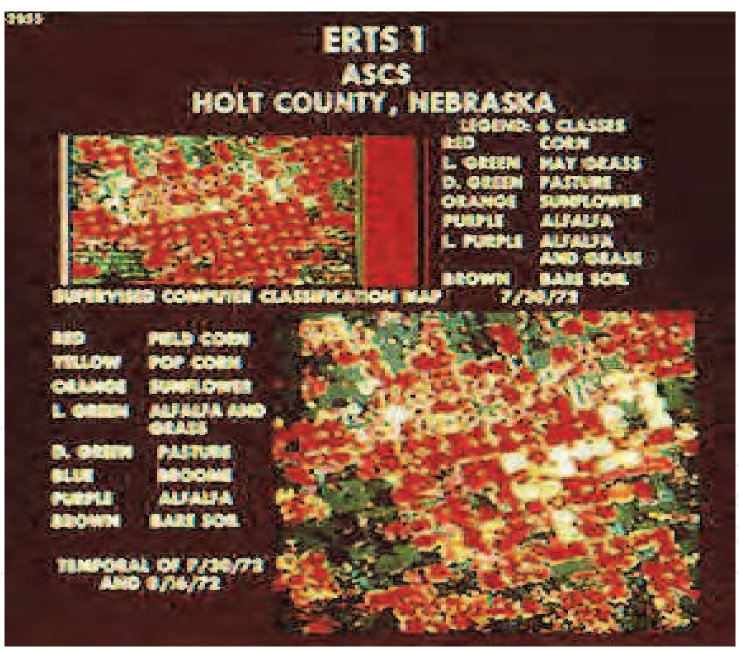


Fig. 23. ERTS-1 classification of several crop types being grown in Holt County, Nebraska

This is a good point in the discussion to introduce the appearance of large area croplands as they are seen in Landsat images. We illustrate with imagery that covers the two major crop growing areas of the United States. The scene below is a part of the Great or Central Valley California, specifically the San Joaquin Valley. Agricultural here is primarily associated with such cash crops as barley, alfalfa, sugar beets, beans, tomatoes, cotton, grapes, and peach and walnut trees. In July of 1972 most of these fields are nearing full growth. Irrigation from the Sierra Nevada, whose foothills are in the upper right, compensates for the sparsity or rain in summer months (temperatures can be near 100° F). The eastern Coast Ranges appear at the lower left. The yellow-brown and blue areas flanking the Valley crops are grasslands and chapparal best suited for cattle grazing. The blue areas within the croplands (near the top) are the cities of Stockton and Modesto.

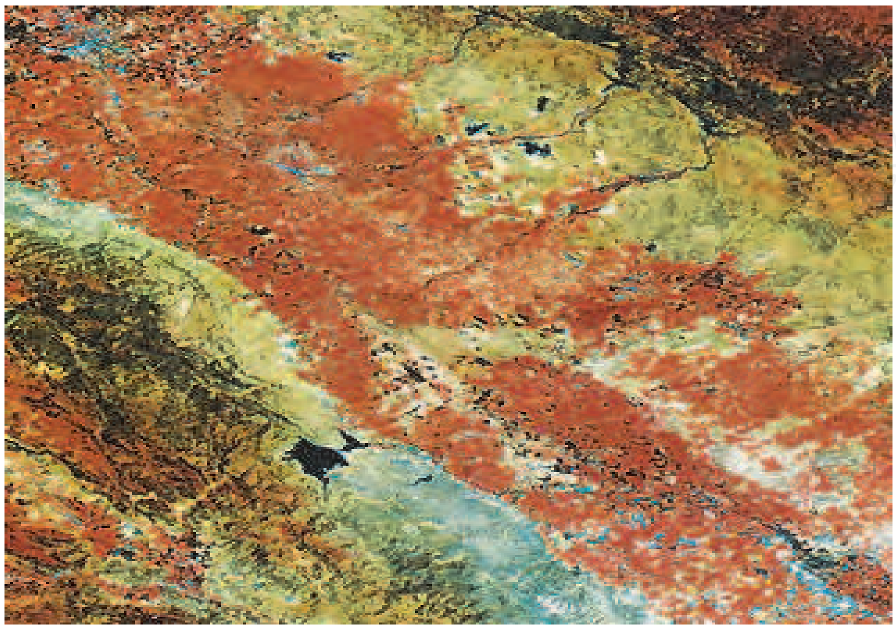


Fig. 24. Landsat imagery of Great or Central Valley of California.

Many factors combine to cause small to large differences in spectral signatures for the varieties of crops cultivated by man. Generally, we must determine the signature for each crop in a region from representative samples at specific times. However, some crop types have quite similar spectral responses at equivalent growth stages. The differences between crop (plant) types can be fairly small in the Near-Infrared, as shown in these spectral signatures (in which other variables such as soil type, ground moisture, etc. are in effect held constant).

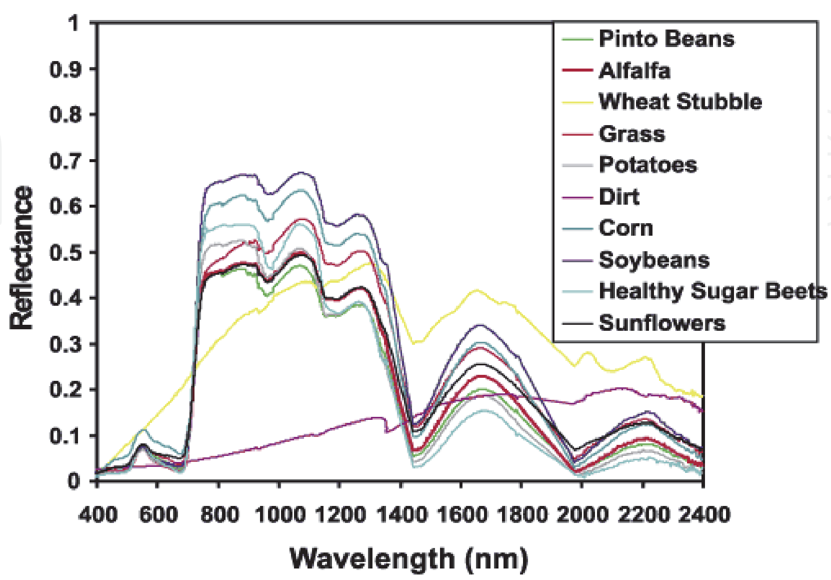


Fig. 25. Spectral responses of different crops

The shape of these curves is almost identical when each crop type is compared with the others. The big difference is in the percent reflectance. The similarity in shape is explained by the fact, discussed earlier, that most vegetation matter has the same basic cell structure and similar content of chlorophyll. Yet remote sensing is reasonably effective at distinguishing and identifying different crop types.

2.6.2 Factors affecting spectral signatures of field crops

Read the answer to this question - it is important. The list is incomplete, but the main factors are discussed. But with so many variables involved, it is difficult to claim that each crop has a specific spectral signature. This means that, in order to identify the several crops usually present in agricultural terrain in any particular area, the most efficient course is to establish training sites, spectral characteristics are one means of identifying and classifying features in a scene. We will see how reliable this is by itself as this Section unfolds. Shape and pattern recognition are valuable inputs in determining what a feature is. The geometric shape of a field of crops sometimes is helpful in determining the actual crop itself. But field shapes tend to vary both within regions of large countries like the U.S. and in different parts of the world. This variation is evident in the illustration below

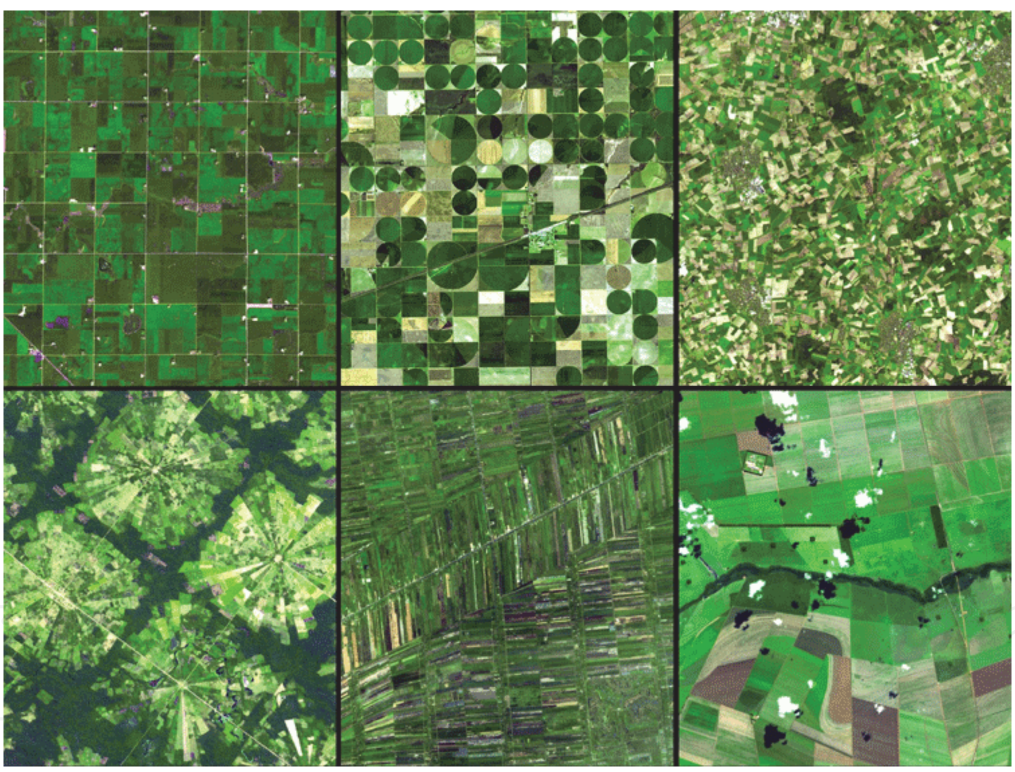


Fig. 26. Landsat image showing the geometric shape of a field of different crops

Through remote sensing it is possible to quantify on a global scale the total acreage dedicated to these and other crops at any time. Of particular import is the utility of space observations to accurately estimate (goal: best case 90%) the expected yields (production in bushels or other units) of each crop, locally, regionally or globally. We can do this by first computing the areas dedicated to each crop, and then incorporating reliable yield assessments per unit area, which agronomists can measure at representative ground-truth sites. Reliability is enhanced by using the repeat coverage of the croplands afforded by the cyclical satellite orbits assuming, of course, cloud cover is sparse enough to foster several good looks during the growing season. Usually, the yield estimates obtained from satellite data are more comprehensive and earlier (often by weeks) than determined conventionally as harvesting approaches. Information about soil moisture content, often critical to good production, can be qualitatively (and under favourable conditions, quantitatively) appraised with certain satellite observations; that information can be used to warn farmers of any impending drought conditions.

Under suitable circumstances, it is feasible to detect crop stress generally from moisture deficiency or disease and pests, and sometimes suggest treatment before the farmers become aware of problems. Stress is indicated by a progressive decrease in Near-IR reflectance accompanied by a reversal in Short-Wave IR reflectance, as shown in this general diagram:

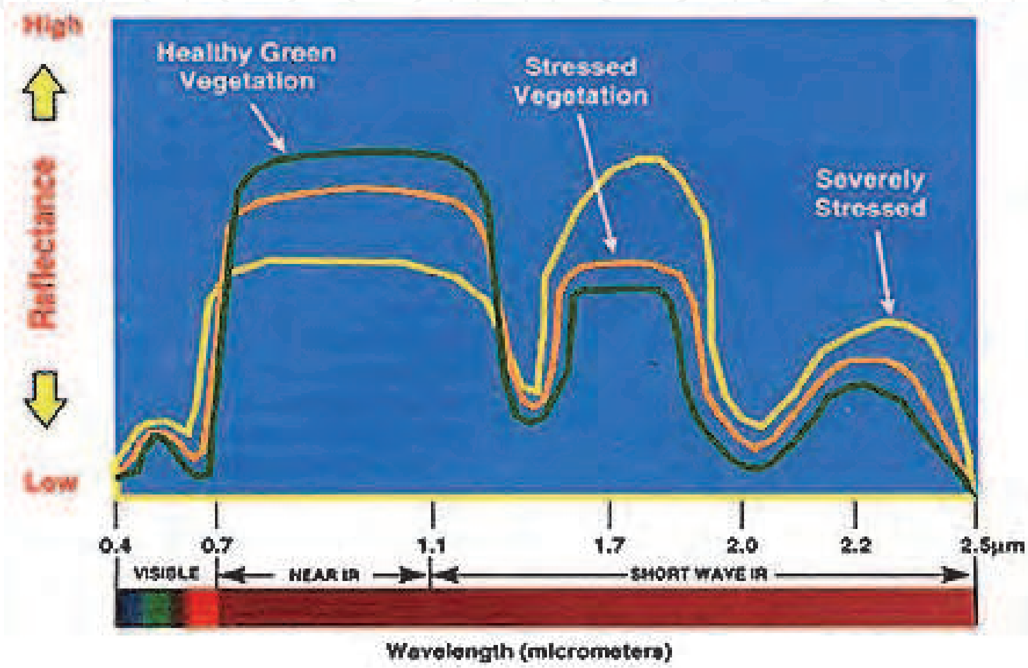


Fig. 27. Crop stress by high and low reflectance

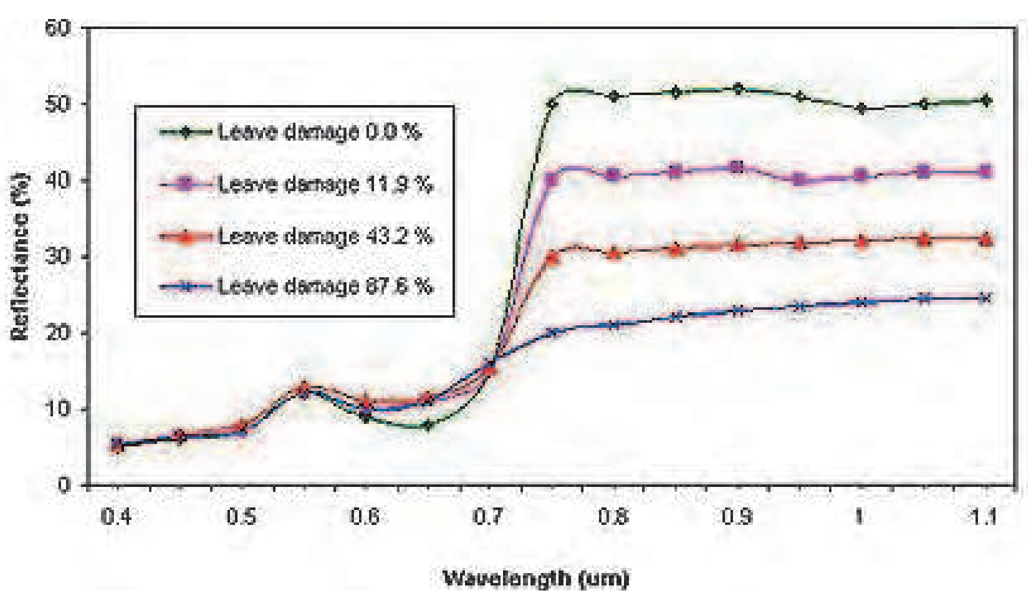


Fig. 28. Soybean plant leaves indicating patterns of high and low reflectance

This effect is evidenced quantitatively in this set of field spectral measurements of leaves taken from soybean plants as these underwent increasing stress that causes loss of water and breakdown of cell walls.
For the soybeans, the major change with progressive stress is the decrease in infrared reflectances. In the visible, the change may be limited to color modification (loss of greenness), as indicated in this sugar beets example, in which the leaves have browned:

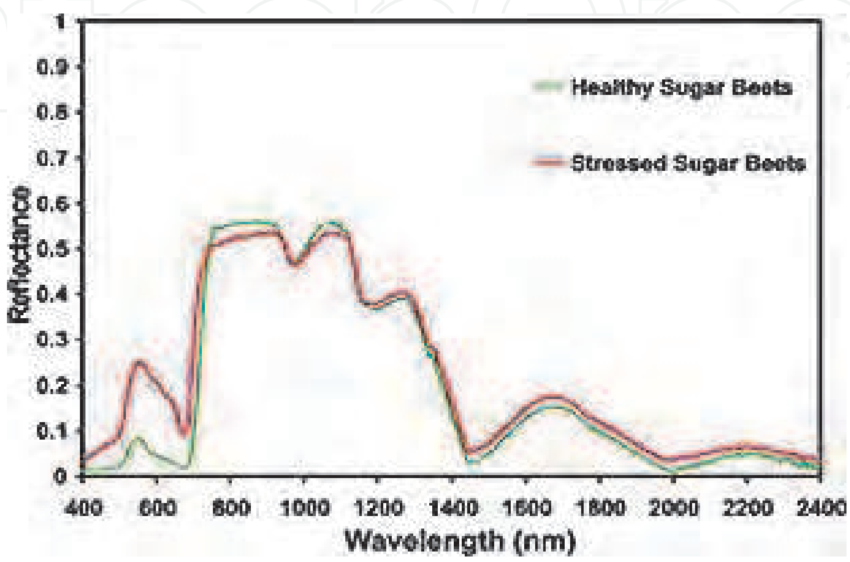


Fig. 29. Sugar beets indicating patterns of high and low reflectance

Differences in vegetation vigour, resulting from variable stress, are especially evident when Near Infrared imagery or data are used. In this aerial photo made with Colour IR film shows a woodlands with healthy trees in red, and "sick" (stressed) vegetation in yellow-white (the red no longer dominates):

Fig. 30. Colour IR film of woodland showing high and low stress

For identifying crops, two important parameters are the size and shape of the crop type. For example, soybeans have spread out leaf clumps and corn has tall stalks with long, narrow leaves and thin, tassle-topped stems. Wheat (in the cereal grass family) has long thin central stems with a few small, bent leaves on short branches, all topped by a head containing the kernels from which flour is made. Other considerations are the surface area of individual leaves, the plant height and amount of shadow it casts, and the spacing or other planting geometries of row crops (the normal arrangement of legumes, feed crops, and fruit orchards). The stage of growth (degree of crop maturity) is also a factor. For example during its development wheat passes through several distinct steps such as developing its kernel-bearing head and changing from shades of green to golden-brown.

Another related parameter is Leaf Area Index (LAI), defined as the ratio of one-half the total area of leaves (the other half is the underside) in vegetation to the total surface area containing that vegetation. If all the leaves were removed from a tree canopy and laid on the ground, their combined areas relative to the ground area projected beneath the canopy would be some number greater than 1 but usually less than 10. As a tree, for example, fully leaves, it will produce some LAI value that is dependent on leaf size and shape, the number of limbs, and other factors. The LAI is related to the the total biomass (amount of vegetative matter [live and dead] per unit area, usually measured in units of tons or kilograms per hectare [2.47 acres]) in the plant and to various measures of Vegetation Index. Estimates of biomass can be carried out with variable reliability using remote sensing inputs, provided there is good supporting field data and the quantitative (mathematical) models are efficient. Both LAI and NDVI are used in the calculations.

Satellite remote sensing is an excellent means of determining LAI on a regional or sub continental scale. In principal, actual LAI must be determined on site directly by stripping off all leaves, but in practice it can be estimated by statistical sampling or by measuring some property such as reflectance. Thus, remote sensing can determine an LAI estimate if the reflectance are matched with appropriate field truth. For remotely sensed crops, LAI is

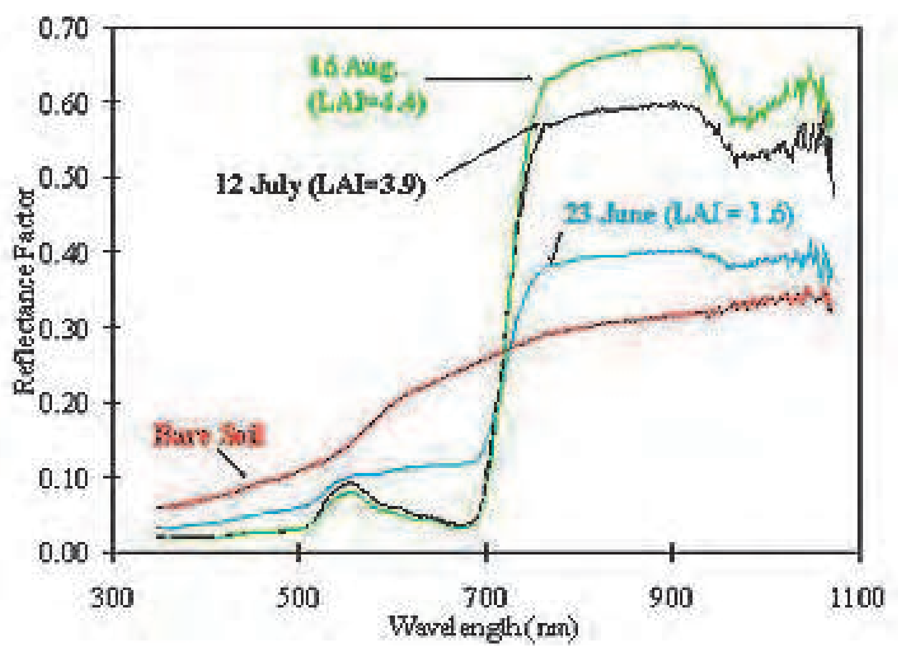


Fig. 31. IR reflectance of corn and soil with LAI

influenced by the amount of reflecting soil between plant (thus looking straight down will see both corn and soil but at maturity a cornfield seems closely spaced when viewed from the side). For the spectral signatures shown below, the Near IR reflectances will increase with LAI. This change in appearance and extent of surface area coverage over time is the hallmark of vegetation as compared with most other categories of ground features (especially those not weather-related). Crops in particular show strong changes in the course of a growing season, as illustrated here for these three stages - bare soil in field (A); full growth (B); fall senescence (C), seen in a false colour rendition:

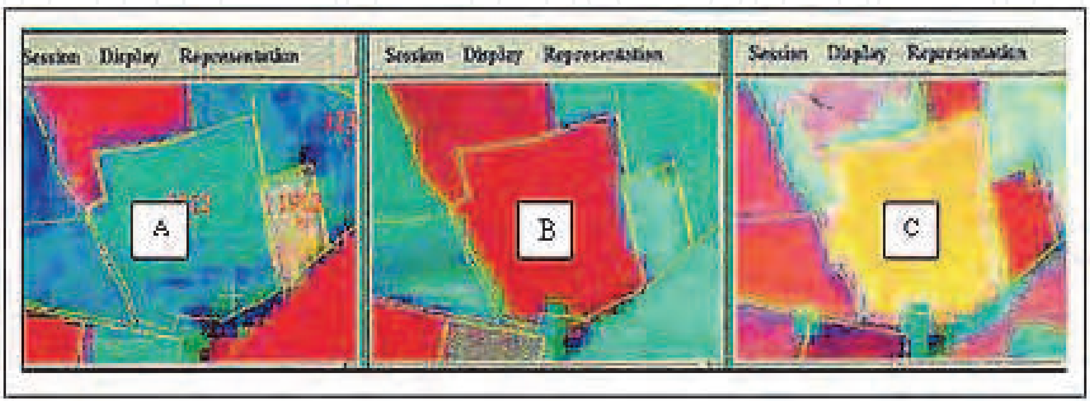


Fig. 32. Land sat image of the field showing three stages - bare soil in field (A); full growth (B); fall senescence (C)

2.6.3 Detection of dead vegetation by Landsat

The study of vegetation dynamics in terms of climatically-driven changes that take place over a growing season is called *phenology*. A good example of how repetitive satellite observations can provide updated information on the phenological history of natural vegetation and crops during a single cycle of Spring-Summer growth is this sequence of

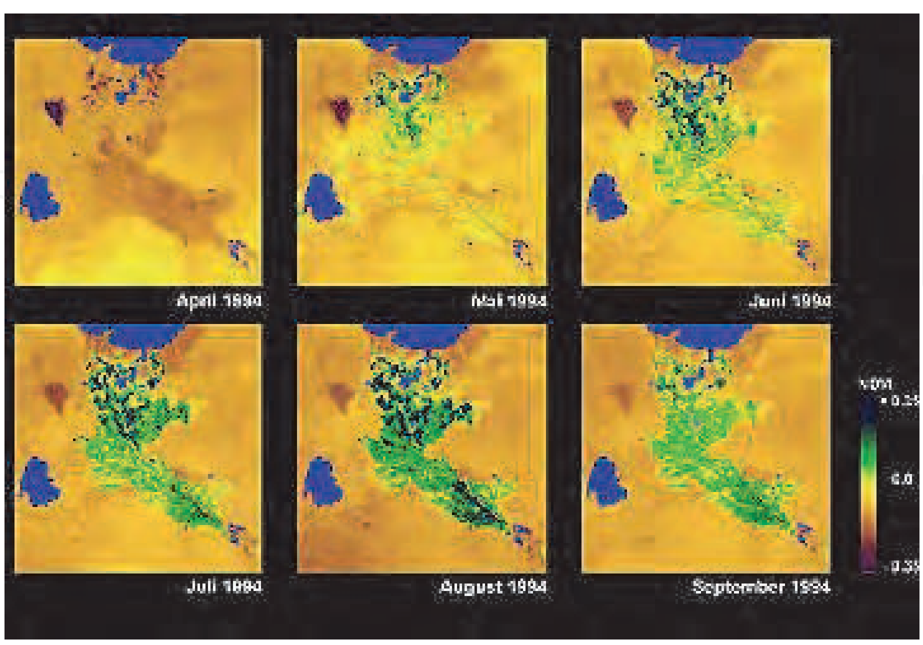


Fig. 33. AVHRR images of the Amu-Dar'ja Delta, south of the Aral Sea in Ujbekistan

AVHRR images of the Amu-Dar'ja Delta just south of the Aral Sea in Ujbekistan (south-central Asia).The amount of vegetation present in the delta (a major farming district for this region) is expressed as the NDVI. The Aral Sea - a large inland lake - is now rapidly drying up. More generally, seasonal change appears each year with the "greening" that comes with the advent of Spring into Summer as both trees and grasses commence their annual growth. The leafing of trees in particular results in whole regions becoming dominated by active vegetation that is evident when rendered in a multispectral image in green tones. The MODIS sensor on Terra has several vegetation-sensitive bands used to calculate a variation of the NDVI called the Enhanced Vegetation Index (EVI).
Now, to emphasize the variability of the spectral response of crops over time, we show these phonological stages for wheat in this sequential illustration:

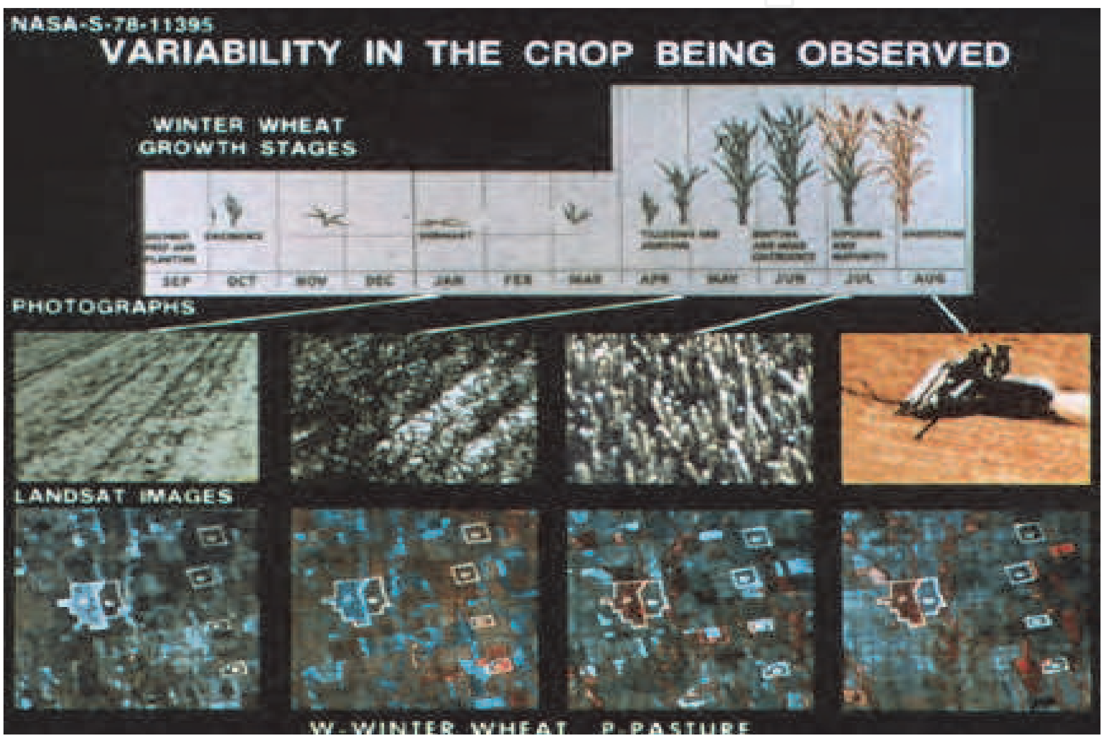


Fig. 34. Enhanced Vegetation Index (EVI) showing variability of the spectral response of crops over time

Note that, in the Landsat imagery, the wheat fields (particularly the light-blue polygon in the far-left image) show their brightest response in the IR (hence red) during the emergent stage but become less responsive by the ripening stage. The grasses and alfalfa that make up pasture crops mature (redden) much later.

2.6.4 Usage of specific crop types as training sites identified (determined)?

With this survey of the role of several variables in determining crop types, let us look now at one of the most successful classifications reported to date. These are being achieved by hyper spectral sensors such as AVIRIS and Hyperion. The Hyperion hyper spectral sensor on NASA's EO-1 has procured multichannel data for the Coleambally test area in Malaysia. This image, made from 3 narrow channels in the visible-Near IR, shows how the fields of corn, rice, and soybeans changed their reflectance during the (southern hemisphere) growing season: Notice the pronounced differences in crop shapes which is a big factor in producing the reflectance differences (as said above, healthy leaf vegetation generally has a spectral response that does not vary much in percent reflectance from one plant type to others, so that differences in crop shape become the distinguishing factor).

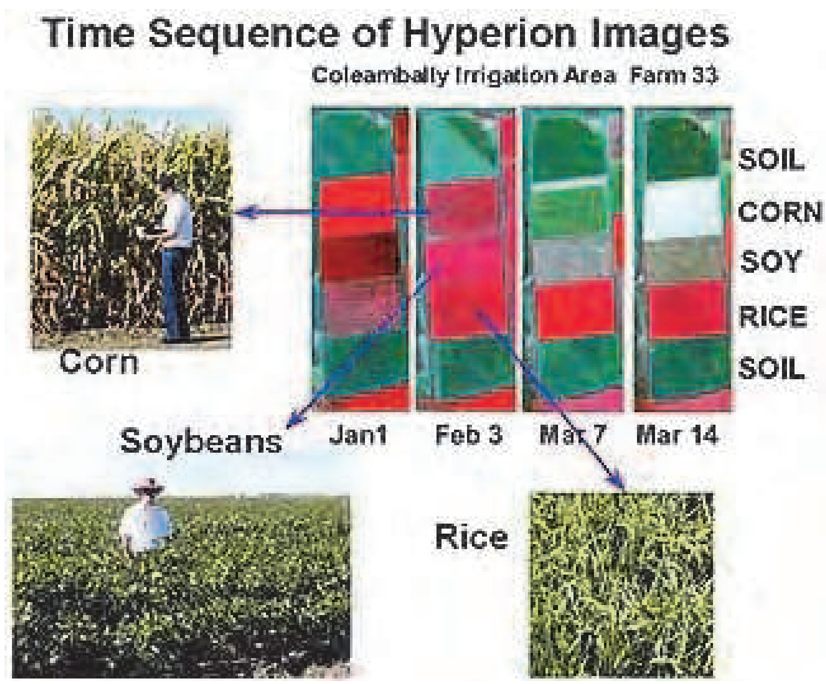


Fig. 35. Visible-Near IR image showing reflectance changing in the fields of corn, rice, and soybeans during the growing season

The multichannel data from Hyperion were used to plot the observed spectral signatures for the soil and three crops, as shown here (the curves identified in the upper right [the writing is too small to be decipherable on most screens] are, from top to bottom, soil, corn, rice, and soybeans):

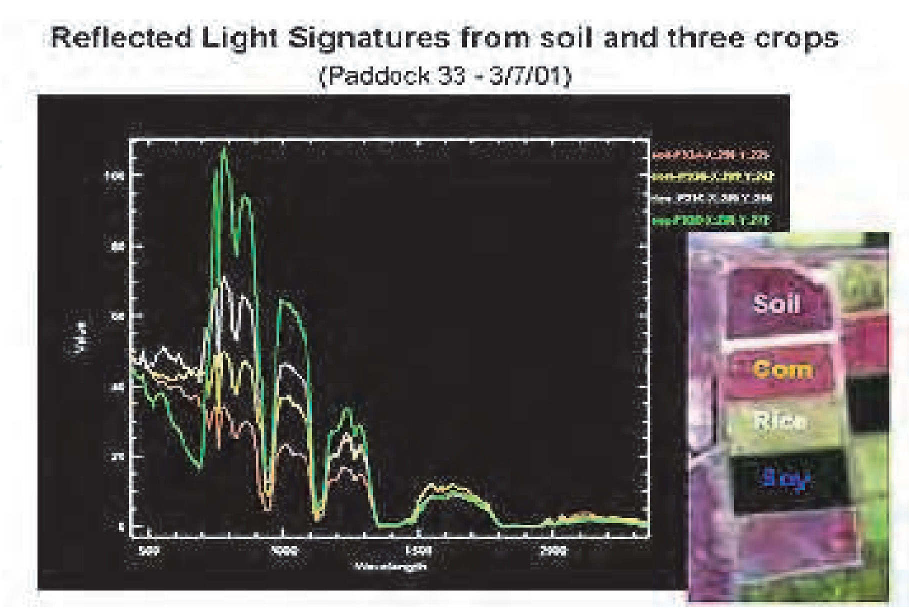


Fig. 36. Reflected light signatures from soil and three crops

Using a large number of selected individual Hyperion channels, this supervised classification of the four classes in the sub scene was generated; this end result is more accurate than is normally achievable with broad band data such as obtained by Landsat:
Active microwave sensors, or radar, can use several variables to recognize crop vegetation and even develop a classification of crop types. Here is a SIR-C (Space Shuttle) image of farmland in the Netherlands, taken on April 4, 1994. The false colour composite was made with L-band in the HH polarization mode = red; L-band HV = green; and C-band HH = blue.

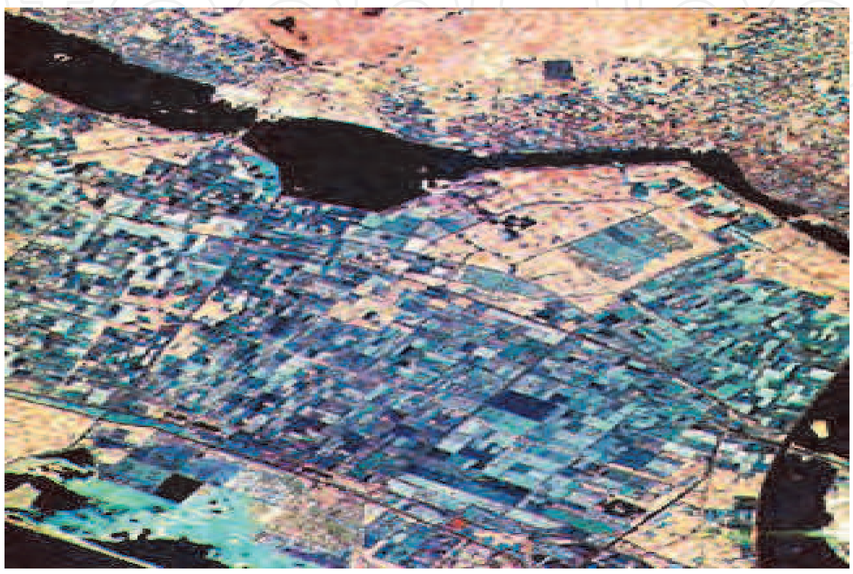


Fig. 37. SIR-C (Space Shuttle) image of farmland in the Netherlands

An additional image variable is the crop's background, namely the nurturing soil, whose colour and other properties can change with the particular soil type, and whose reflectance depends on the amount of moisture it holds. Moisture tends to darken a given soil colour; this condition is readily picked up in aircraft imagery as seen in this pair of images:

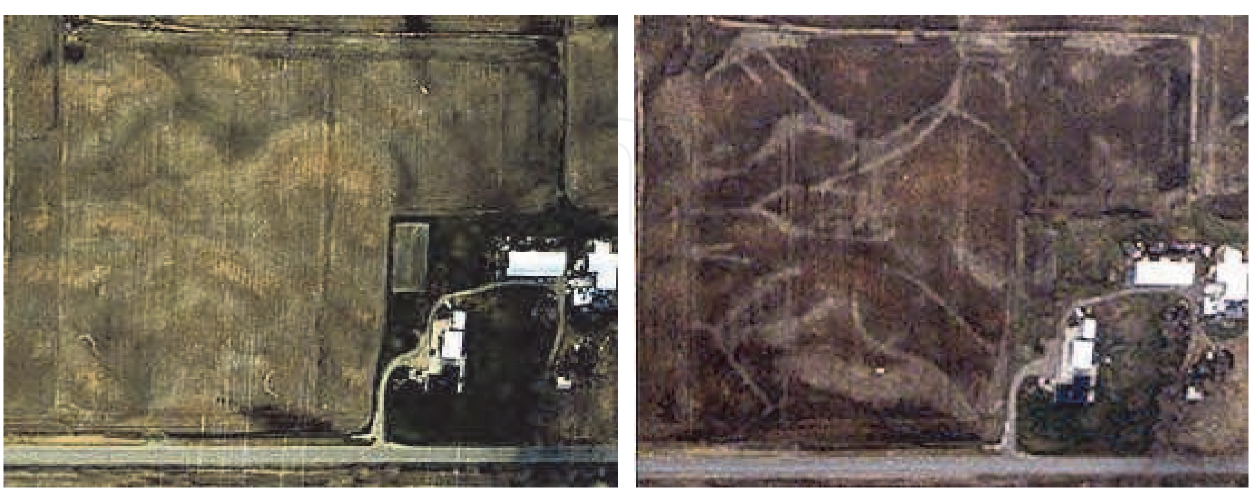


Fig. 38. Aircraft imagery showing different colours due to moisture pickup

Often, the distribution of moisture, as soil dries differentially, is variable in an imaged barren field giving rise to a mottled or blotchy appearance. Thermal imagery brings out the differential soil moisture content by virtue of temperature variations. The amount of water in the crop itself also affects the sensed temperature (stressed [water deficient] or diseased crop material is generally warmer). Soil water variations are evident in this image made by an airborne thermal sensor of several fields, where high moisture correlates with blue and drier parts of the fields with reds and yellows:

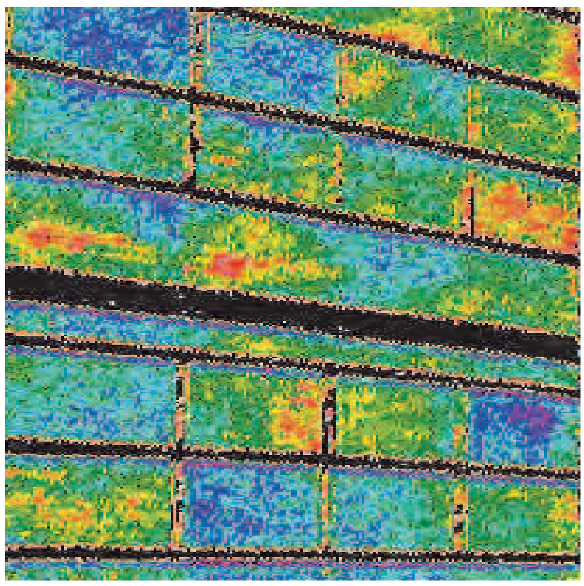


Fig. 39. Image made by an airborne thermal sensor of several fields showing the soil water variations

A combination of visible, NIR, and thermal bands can pick up both water deficiency and the resulting stress on the crops in the fields. This set of three images was made by a Daedalus instrument flown on an aircraft. In the top image, yellow marks unplanted fields and those in blue and green are growing crops. The center image picks up patterns of water distribution in the crop fields. The bottom image shows levels of stress related in part to insufficient moisture.

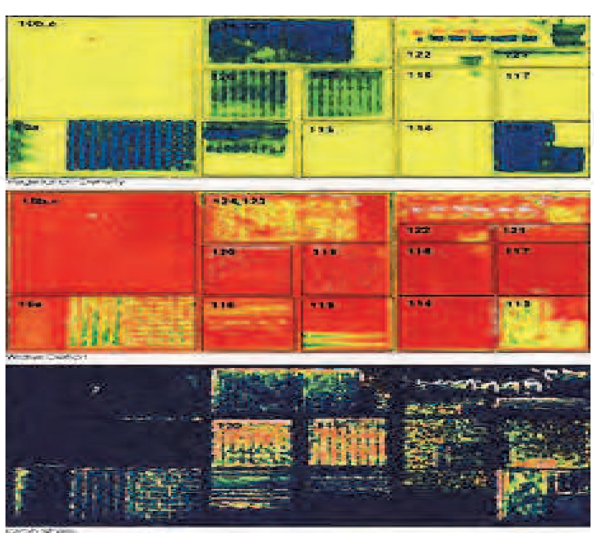


Fig. 40. Image showing levels of stress related in part to insufficient moisture

A passive microwave sensor also picks up soil moisture. Cooler areas appear dark in images of fields over flown by a microwave sensor - although other factors, such as absence or presence of growing crops (and their types) besides moisture can account for some darker tones.

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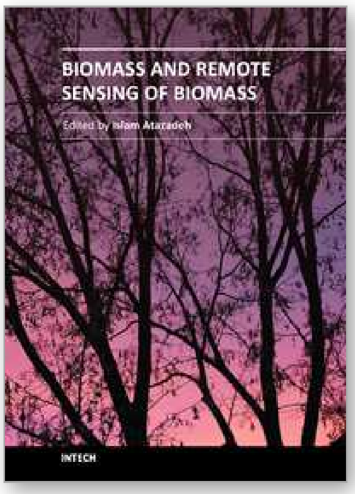

Biomass and Remote Sensing of Biomass

Edited by Dr. Islam Atazadeh

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Generally, the term biomass is used for all materials originating from photosynthesis. However, biomass can equally apply to animals. Conservation and management of biomass is very important. There are various ways and methods for biomass evaluation. One of these methods is remote sensing. Remote sensing provides information about biomass, but also about biodiversity and environmental factors estimation over a wide area. The great potential of remote sensing has received considerable attention over the last few decades in many different areas in biological sciences including nutrient status assessment, weed abundance, deforestation, glacial features in Arctic and Antarctic regions, depth sounding of coastal and ocean depths, and density mapping. The salient features of the book include:
Several aspects of biomass study and survey
Use of remote sensing for evaluation of biomass
Evaluation of carbon storage in ecosystems
Evaluation of primary productivity through case studies

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