Unit I
Basics of Remote Sensing

Session 3
Energy Interactions with Earth Surface Features

Department of Civil Engineering
The Open University of Sri Lanka

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Session 3 – Energy Interactions with Earth Surface Features

Introduction

There are fundamental energy interactions with earth surface features when electromagnetic energy reaches the surface. The spectral reflectance of vegetation, soil and water will vary thus enabling us to identify each type of surface feature. We can analyses digital images by studying the spectral response patterns and can gather information from remotely sensed images.

Aim:

❖To teach about energy interactions with earth surface features.

3.1 Introduction to energy interactions with earth surface features

We have said that the electromagnetic energy from the sun bathes our planet with light waves and other frequency waves, which are not visible to the eye.

What happens to the electromagnetic energy when it encounters earth surface features?

Three fundamental energy interactions with the features, are possible.

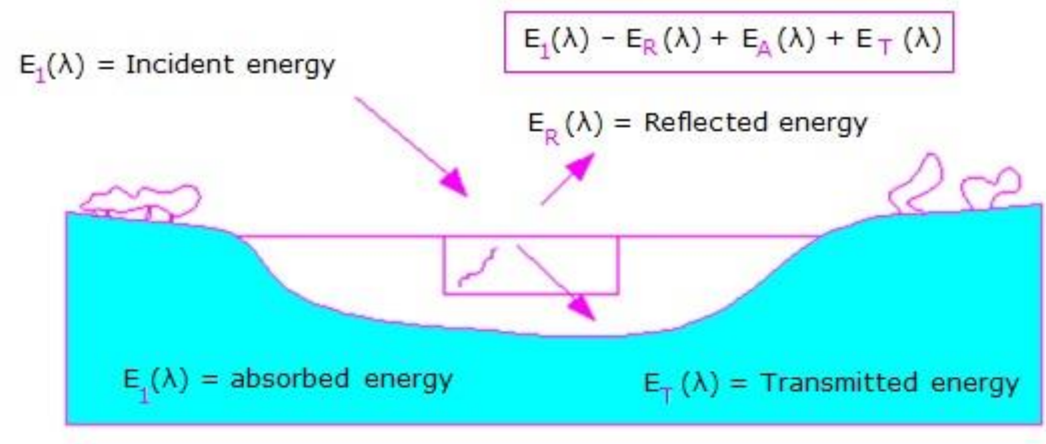

Figure 3.1: Figure giving the interactions

Applying the principle of conservation of energy,

Incident energy = reflected energy + absorbed energy + transmitted energy

$$Ei\ (\lambda) = Er\ (\lambda) + Ea\ (\lambda) + Et\ (\lambda)$$

All energy components are a function of the wavelength λ.

Ei= incident energy	Er= reflected energy
Ea= absorbed energy	Et= transmitted energy

There are two important points to be noted regarding the above relationship.

1. The proportions of energy reflected, absorbed, and transmitted will vary for different earth features. This will depend on their material type, their form and condition. The reflected energy is referred to as the 'spectral content'. The differences in the spectral reflectance, which can be due to many reasons (to be discussed), permit us to distinguish features on an image.

2. We know that the energy is a function of the wavelength. So, even within a given feature type, the proportion of reflected, absorbed, and transmitted energy will vary at different wavelengths.

Let us examine and see what the implications of the above energy relationship are with respect to image interpretation.

3.1.1 Effect of the Earth surface features and the wavelength, on reflectance pattern

Reflectance is a measure of the incident energy that is reflected. Surface texture affects the way how energy is reflected from an object. Ability of our eye to distinguish between the colours on various features is also a measure of the reflectance. Reflectance characteristics play a major role in recognizing surface features and in deciding the wavelength ranges to be used for different applications. Let us examine their effect.

3.1.1.2 Reflectance and surface texture

Let us see the first implication of the energy relationship mentioned above on interpretation of images.
It is the effect of the Earth surface features to reflect wavelengths of the radiation, differently.

Let us see the reasons for this.
Many remote sensing systems operate in the wavelength regions in which reflected energy predominates. Hence the reflectance properties of earth features are very important. So, let us restructure our energy balance equation in the following manner.

Reflected energy = incident energy – (absorbed energy + transmitted energy)

$$Er(\lambda) = Ei(\lambda) - [Ea(\lambda) + Et(\lambda)]$$

Let us first consider how an object reflects energy, varies.

The variation is primarily a function of the surface roughness of the object relative to the wavelength.

Roughness depends on the relative wavelength in comparison to the surface of the objects.

Specular reflectors are flat surfaces acting like mirror reflectors. When the wavelength of the incident energy is large in comparison to the surface roughness or surface height variations, such a surface will act as a near-perfect specular reflector.

Diffuse reflectors are rough surfaces and reflect uniformly in all directions. In contrast to the above case, here the wavelengths of the incident energy are much smaller than the surface height variations, that surface will act as a near -perfect diffuse reflector.

Which type of surface do you think will send the most signals to the sensor receiver? If you examine the reflectance pattern of the various surfaces in the figure you will be able to give an answer.

Yes, when you consider the practical situation, it is generally the near-perfect diffuse reflector. Here as you can see there is much greater chance for reflected radiation to reach the sensor.

For the wavelengths of visible and infrared (IR) energy most objects act as 'near-perfect diffuse reflectors'. Therefore, we can sense in these wavelength ranges to obtain most feature details.
In microwave remote sensing this surface roughness becomes much more important as we shall see later.

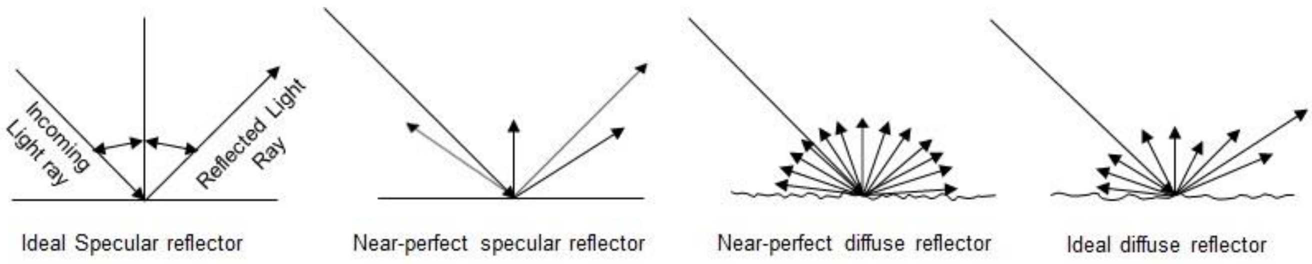

Figure 3.2: Figure of Specular vs Diffuse reflectance

So, from this we can deduce the following.
If we can compare the surface roughness with the wavelength of the incident energy, we can envisage what type of reflector the observed Earth's features will act as for that wavelength.

To be able to understand this, let us think that we are aware of the wavelength used for sensing, in relation to the surface roughness of the feature to be observed. If so, we can have an idea of the reflection pattern. It can be either 'near-perfect specular reflector or 'near-perfect diffuse reflector'.

For an application, we could decide on one of the above categories of geometric manner of reflection, depending on the surfaces roughness in comparison to the wavelength of the energy incident upon it.

A sandy beach can appear as follows to incident energy;

- In the relatively long wavelength radio range it will appear smooth.
- In the visible portion of the spectrum it will appear rough.

What do we gather from this observation?

When the wavelength of incident energy is much smaller than the surface height variations or the particle sizes that make up a surface, the reflection from the surface is diffuse. For visible and infrared (IR) waves, most features are diffuse reflectors.

Having seen the possible types of reflections, let us see how this affects the sensing; With reference to the figures of specular vs diffuse reflectance let us consider the amount of energy received by the sensor.

In the Case (i) Vertical sensors will receive no signal, but an oblique sensor receives the total amount.
Case (ii) Vertical sensor will not receive a signal and an oblique sensor will receive a certain amount only
Case (iii) Vertical sensor will receive a small amount and an oblique sensor will receive a relatively larger amount.
Case (iv) Vertical and oblique sensors will receive equal amounts.
Most natural cases will relate to case (iii).

The capture of diffuse reflectance properties of terrain features is independent of the reflecting direction. That is why we measure diffuse reflectance properties in remote sensing applications.

Having examined the effect of the Earth surface features on the reflectance, now we come to the effect of the wavelength of reflectance. This concerns the 'colour' of the object under observation.

Any type of reflection contains spectral information on the 'colour' of the reflecting surface.

3.1.1.2 Reflectance and colour

Another implication of the energy relationship is, the ability of our eye to distinguish between the colours on various features. This will affect visual interpretation of images. The ability of different sensors to distinguish between non-visible wavelength ranges will affect the interpretation of digital images, which we shall be discussing later.
We have seen what the electromagnetic spectrum is. We refer to ranges of wavelengths in the spectrum as spectral 'bands'.

Two features may be indistinguishable in one spectral band, but they can be very different in another spectral band.

This difference is brought about by the differences in the wavelengths of the reflected radiation. Within the visible portion of the spectrum these spectral variations result in the visual effect called 'colour'. For example, we call objects 'blue' when they reflect more highly in the blue portion of the spectrum, 'green' when they reflect more highly in the green spectral region and so on.

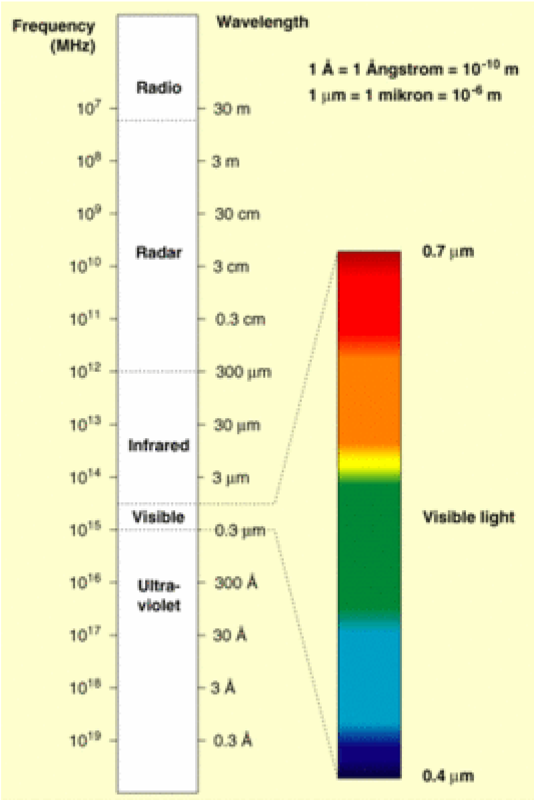

Figure 1.3: Electromagnetic spectrum giving the visible range of colours and their variation with the wavelength

(Source: http://www.esa.int/images/02-spektrum_large,0.gif)

In effect what does the eye do?

The eye utilises spectral variations in the magnitude of reflected energy, measured by very many, very tiny sensors, sensible either in red, green or blue, to discriminate between various objects.

3.2 Spectral reflectance

What can we see from what we have read about so far?

The reflectance of the energy depends mainly on the wavelength. We saw that the reflectance is a function of the wavelength. This depends on which part of the electromagnetic spectrum or the 'spectral region' from which the energy comes.
If we state it in other words, the spectral reflectance of the electromagnetic energy that is incident upon the surface of the Earth, is essential to characterise features.

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We also must consider incidence and reflection directions.

How are the reflectance characteristics of earth surface features quantified?

This is done by measuring the incident energy that is reflected.

This measurement is called 'spectral reflectance'

This is measured as a function of wavelength, ρ.

Spectral Reflectance = Reflected energy/ Incident energy

$\rho = E_r(\beta,\lambda) / E_i(\alpha,\lambda)$

= Energy of wavelength λ and reflecting angle β, reflected from the object/ Energy of wavelength λ and incident angle α, incident upon the object

The graph of the spectral reflectance of an object as a function of wavelength is called the **'spectral reflectance curve'** for that object.

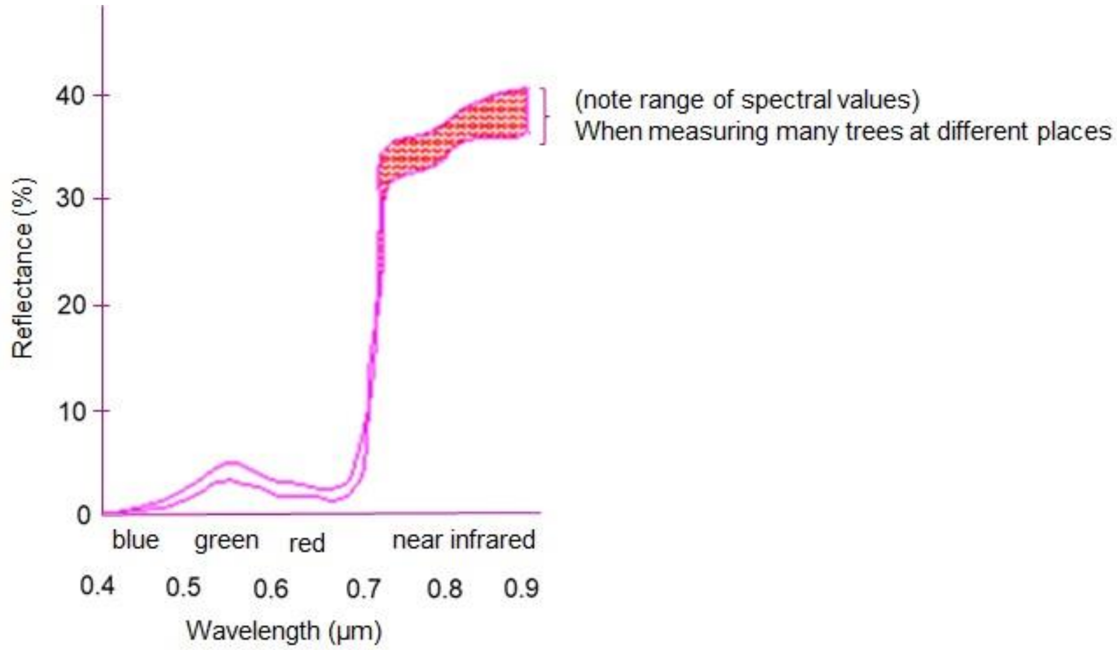

Figure 3.4: Spectral reflectance curve for deciduous (broad leaved) trees.

Note the range of spectral reflectance values at any wavelength (adapted from Kalensky and Wilson, 1975).

We have seen that remote sensing means measuring without physical contact. Eyesight is a form of remote sensing. When the eye sees an object, the electromagnetic radiation, which is the reflected light from the surface of the object, is registered. The radiation contains information about the surface, and we see colour and form. In the same way, a scanner in a satellite also records electromagnetic radiation.

How does a white surface look white?
Why do leaves look green?

A white surface reflects equal amounts of radiation of all wavelengths of visible light. A green leaf will reflect less radiation in the red and blue parts of the visible spectrum. Since more green light is reflected, the leaf looks green. Now we shall go on to examine the reflectance with a little more detail.

The figure below shows typical average spectral reflectance curves for three basic types of earth features; healthy green vegetation, dry bare soil and clear lake water. These average value curves demonstrate some fundamental points concerning spectral reflectance.

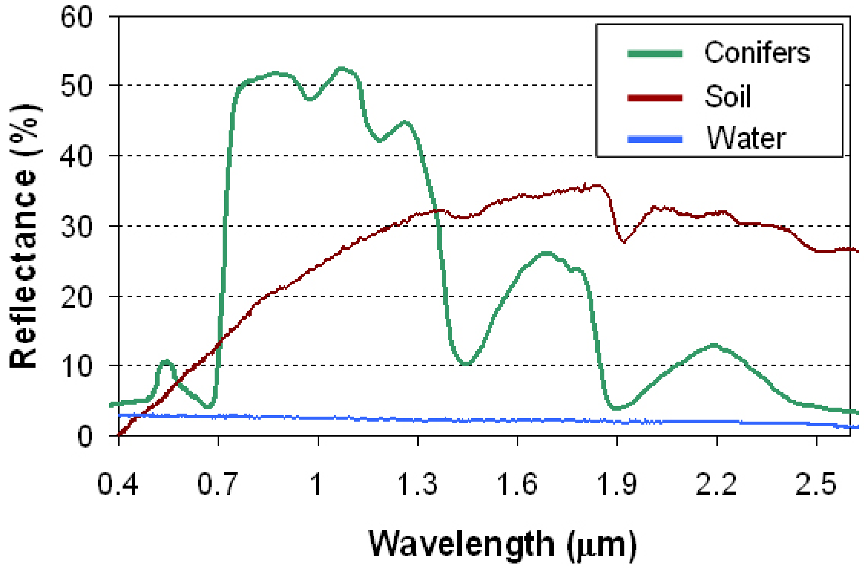

Figure 3.2: Figure of typical spectral reflectance curves for vegetation, soil and water. (measured by a continuously measuring radiometer)

(Source: http://www.eumetrain.org/data/3/36/flash/210.jpg)

Let us consider the curve for vegetation.

Reflectance in the visible portion

In the visible portion of the spectrum from 0.4 to 0.7 µm, chlorophyll strongly absorbs the blue and red energy. Reflection of green energy is very high. Hence, we see leaves as green. When vegetation is under stress, which interrupts normal growth, chlorophyll production will decrease considerably, and red reflectance will increase making us see plants as yellow, which is a combination of green and red.

Reflectance in the near-IR portion

In the near-IR portion of the spectrum from 0.7 to 1.3 μm, a plant leaf reflects about 50% of the energy incident upon it and the balance is transmitted. Absorption is minimal in this range. The reflectance in this range is due to the internal structure of the plant leaves. Even if plants look the same in the visible range, the difference in the internal structure helps to identify plant species by reflectance measurements in the near-IR range.

Now let us consider the curve for soil.

When you consider the curve for soil, factors affecting soil reflectance are, moisture content, soil texture, surface roughness, presence of iron oxide and organic matter. Since vegetation has a remarkably high reflection in the near infrared wavelength and a low reflection in the visible red range, this makes it possible to distinguish vegetation areas from bare ground. The difference of reflection in the near infrared and the red wavelength range is great for vegetation areas and insignificant for bare ground.

Surface roughness would become important in microwave remote sensing, much further down in the electromagnetic spectrum.

Now consider the curve for water.

Water absorbs energy in the wavelengths near-IR and beyond. Hence water areas appear dark in satellite images sensed in these wavelengths. When you consider the visible wavelengths, the reflectance sensed from a water body, which will give information about the water body, will be the waves, which interact with the water's upper layer (see figure), and not the waves, which reflect off the surface of the water. Visible waves can also interact with material suspended in the water, or with the bottom of the water body, if shallow, and be reflected towards the sensor. The material suspended in the water can be inorganic suspended matter, or phytoplankton. Dissolved organic matter will absorb the waves.

3.3 Spectral Response Patterns

Spectral Signature

Having looked at the spectral reflectance characteristics of vegetation, soil and water, we should now understand that it is possible to 'spectrally separate' features of this type. The amount of separation will depend on **'where we look'** in the electromagnetic spectrum. Looking at the above graph you may see that, water and vegetation, reflect nearly the same in visible wavelengths but in near-IR wavelengths they are distinctly separable.

Spectral responses measured by remote sensors over various features make it possible for us to assess the type and condition of the features under observation. The spectral responses can be from wavelengths of any part of the spectrum relevant for the application.

'Spectral Signature' of a surface feature is the radiation reflected and is given as a function of the wavelength.

The word 'signature', refers to a distinguishing characteristic.

In Remote Sensing, a **'spectral signature'** of a feature comprises a set of values for the **reflectance** or the **radiance** of the feature, where each value corresponds to the reflectance or radiance averaged over a different, well-defined wavelength interval.

Given below are some spectral signatures or spectral reflectance curves for various Earth's features.

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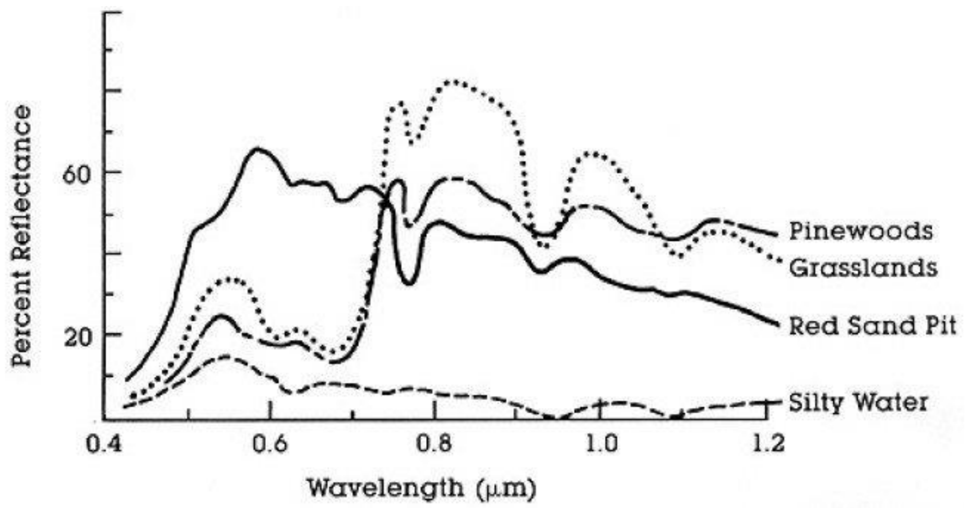


Figure 3.6: Spectral signatures or spectral response patterns.
(Source: http://semiautomaticclassificationmanual-v4.readthedocs.io/en/latest/_images/Spectral_Reflectance_NASA.jpg)

The spectral signature, given in terms of *spectral radiance*, is not constant for a given feature because it depends on the varying spectral irradiance due to the sun and sky. A more constant and better measure of spectral signature is the *spectral reflectance*, as it gives the variations in spectral irradiance. However even this measure of the spectral signature should be corrected for atmospheric effects.

It should be clear to you now that the composition of the electromagnetic reflection, the 'spectral signature', tells us about the surface emitting or reflecting radiation. *Sensors aboard satellites can distinguish between various spectral signatures and this ability is used in mapping out different surface and area types.*

For a particular sensor or sensors with similar spectral resolution (sensors where the wavelength ranges of the different bands are similar), the spectral signature of a particular feature will be unique.

The satellite scanner will process the spectral signatures as digital values.

What can we deduce from the definition of the spectral signature?

Provided a similar number of electromagnetic wavelength intervals are used within the same range, through which observations are recorded (the number of bands and the range for each band used are the same), the spectral signature will be unique for a given feature. So, we can use the spectral signature to identify similar feature types on the Earths' surface.

When using the term 'spectral signature' you should also keep in mind the variability of spectral signatures. How does this variability come about?

In a laboratory, a spectral signature is obtained from measurements using a spectrophotometer. The measurements give the distribution of reflectance of a material as a function of wavelength compared to that of a diffuse white surface. The range of the wavelength considered is the spectral resolution. The spectral resolution of the measurements made in the laboratory is generally about 0.001μm. But we normally do not measure in such high spectral resolutions when measuring with sensors on satellites.

Consider an image where the spectral resolution is say 0.1 μm. If four such bands are used, then four discrete spectral intervals will cover the spectral region of 0.4 μm. But when using the spectrophotometer this same region will be covered by 400 spectral intervals!

Using four bands the possibility is that we may not obtain a unique spectral signature for similar features. Hence you can see that the lower order of the spectral resolution makes it more difficult to discriminate materials having roughly the same spectral reflectance properties. In other words, the spectral signature obtained may not be unique.
Hence the spectral reflectance characteristics actually result in 'spectral response patterns'.

In remote sensing applications, we can also identify the condition of objects of the same type, if we rely on spectral response pattern variability to derive this information. One such application is to identify stressed vs healthy vegetation within a given species.

The spectral response pattern variability must be carefully studied as well, with respect to various earth surface features if we are to make the maximum use of spectral signature in images.

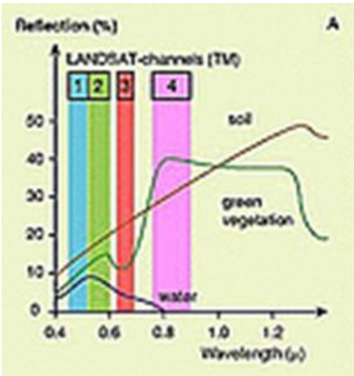
The nature or condition of the ground area under observation is important since it affects spectral response patterns.

It is very important to understand the nature of the ground area one is 'looking at' with remote sensor data, not only to minimize unwanted spectral variability, but also to maximize this variability when the application requires it. Maximising the variability will enhance those features on the image.

Let us look at some factors, which influence the ground area under observation and hence the spectral response patterns.

Activity 3.1

The graphs of spectral signatures of water, soil and vegetation are given below. Indicate the channels in which it is easy to distinguish vegetation areas from bare ground. Explain how this is possible.

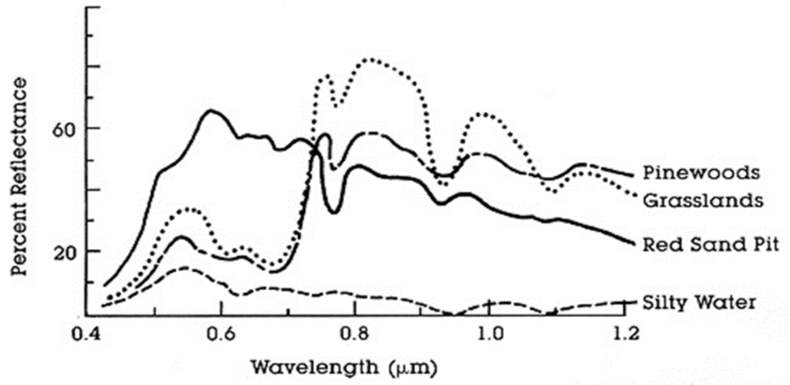


Temporal effects: Temporal effects are any factors that change the spectral characteristics of a feature over time. For example, the spectral characteristics of vegetation generally changed throughout a growing season. These changes can influence the sensor data we collect for a given application.

Spatial effects: Spatial effects refer to factors that cause the same type of features at a given point in time, to have different characteristics at different geographic locations. This will be significant when analysing say vegetation data, hundreds of kilometres apart where entirely different soils, climates, and cultivation practices might exist.

Temporal and spatial effects, wanted or unwanted, can be the key to obtaining information in an analysis. An example in using temporal effects is, in detecting the change in suburban development by using data obtained on two different dates. An example of using spatial effects is, in detecting the change in the leaf morphology of trees when they are subjected to some form of stress.

Activity 3.2



(i) Referring to the above spectral plots, which region of the spectrum shows the greatest reflectance for the following materials?

(a) grasslands

(b) pinewoods

(c) red sand

(d) silty water

Are these four classes distinguishable at 0.6 μm?

(ii) Which material is brightest at 0.6 μm, and which is brightest at 1.2 micrometres?

(iii) What can you separate with a narrow band at 0.73 μm?

3.4 Applications of spectral signatures and spectral response patterns

3.4.1 Vegetation Mapping

If we can distinguish between different surfaces in a certain band of satellite data what can we infer?

It means that the difference in the spectral signature curve for those features is considerable in the wavelength range (band) of observation. So, we make use of the regions in the spectral signature curve, where the difference in the signature becomes maximum and observe in those particular wavelengths (or band of wavelengths).

The figure of reflectance curves given in the figure in section 3.2 above, shows that if you want to distinguish between bare ground and vegetation you should scan in the wavelength ranges of 0.6-0.7 μm and 0.7-0.9 μm. What is the reason for this?

Vegetation will give a strong reflection in the 0.7-0.9 μm area and give a weak reflection in the 0.6-0.7 area. As mentioned before, because the spectral signature of vegetation is so characteristic, the distinction between bare ground and green vegetation normally offers no problems. The difference between the reflection in the visible and the near infrared ranges can, as already mentioned be used to determine the photosynthesis and the growth of plants.

We can use the reflectance of vegetation in some well-defined bands for the calculation of indices, which will indicate the amount of vegetation covered land.

The Normalized Difference Vegetation Index (NDVI) is calculated as follows:

NDVI = near infrared – red / near infrared + red

This is the formula used for mapping the global distribution of vegetation. The software that is used for digital image processing can be used to perform the function of identification of vegetation through the use if the NDVI.

The sensors on National Oceanic and Atmospheric Administration (NOAA) satellite are used for global mapping of vegetation. NDVI is obtained from channel 1 (red) and channel 2 (near infrared) of NOAA. This NDVI indicates the quantity of green plant mass. The greater the NDVI the denser the vegetation. The development of the NDVI during the growing season reflects the plant growth. It is possible to plot the NDVI value for a specific pixel over time, thus monitoring the plant growth for the area the pixel covers. This is known as the NDVI time series.

Vegetation absorbs red and blue energy from white light and reflects green light. It also reflects strongly between 0.7 and 1.0 μm as mentioned earlier. So, vegetation appears bright in the near-IR wavelengths. These properties of vegetation result in significant tonal variations or tonal signatures on multispectral images. Vegetation appears darker in the blue and red bands, somewhat lighter in the green band and lighter and brighter in the near-IR band.

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It is sometimes possible to detect crop stress from moisture deficiency or disease. When using near-IR imagery or aerial photos with colour IR film, healthy vegetation is shown in red and stressed vegetation in blue to yellow-white.

3.4.2 Area Classification

What is classification of an area?

Classification is the process of separating features e.g. water, bare ground, built up areas, vegetation (agriculture, types of forest), urban areas etc. in a reliable image.

The aim of classification of a satellite image is to assign the pixels in the image (see pixel) to specific land cover classes. These classes need to be predefined or created as part of the classification process. You need to have some knowledge of the area or have information about what the different 'features' and 'colours' mean.

What is the channel or band of a satellite sensor?

The channel or band indicates the range of electromagnetic energy as given by the wavelength, which is sensed within that channel/band.

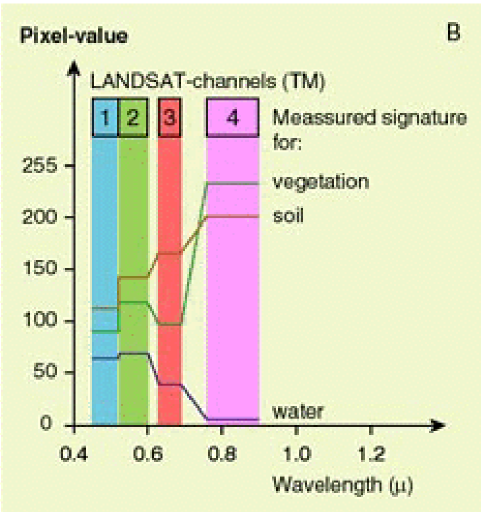

Figure 3.7: Figure giving typical spectral reflectance curve and the different bands.

(Source - http://www.esa.int/images/04b_400.gif)

Each of the satellite sensor channels comprise of the narrow ranges of the spectrum. The bands are chosen in order to optimise the difference in reflection of most land cover types to be separated. This will help in making a good classification.

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How can classification be performed?

The computer can be programmed to attribute the area on an image, to a number of given classes (surface variations) based on the different spectral responses. In effect, the amount of reflectance at any point denoted by a pixel, will be given by a digital number. That is, there will be digital numbers to represent the response characteristics of each pixel area. The numbers can vary from 0-255. The actual values associated with each pixel are analysed mathematically using computer driven algorithms. These algorithms will cluster similar pixels and groups of pixels in to unique classes. By this we can identify the land use patterns.

During the image classification process, it is possible to identify a specific area type on the screen (training area), and then let the computer identify all the pixels having the same or similar response (further explained below). In this way, large regions can be mapped very quickly and easily by means of satellite data. But when spectral response in the available bands, of two types of features are very much alike, it may not be able to classify into two different classes.

The classified map is a thematic map showing the distribution of the selected classes. The number of pixels of each class can be counted and the surface determined (knowing the size of the pixel or the resolution).

There are two types of classification, supervised and unsupervised. In both cases previous knowledge of the imaged scene is highly desirable. These classification processes will be further dealt with in detail in later sessions on image processing. You will also practically apply these techniques by using the computer with the relevant software.

Supervised classification requires at least partial knowledge of the scene area in order to provide the computer with unique material groups or what is called 'training classes'. These are areas, which can be categorised by a previous knowledge of the area. Regions containing a known land cover type within a scene are delineated graphically and stored for use in the supervised classification algorithm. The resulting classification maps should be checked using ground truth information and field validation surveys if possible, and not used previously as training area.

Unsupervised classification algorithms compare pixel values and in an iterative process group them in clusters. The computer is used to assess the inherent variability. In order to find out what each class (i.e. Cluster) may represent in the real world the scene area has to be investigated.

In general, supervised classifications are more accurate than unsupervised. But unsupervised classifications can well be used as a test of separability of required land cover types.

If we further refine the classification process it will be possible to map out vegetation in more land cover classes. One way is to look for sensors with more and more optimised bands in the visible and near infrared ranges of the spectrum. A satellite with many narrow channels is said to have a high degree of spectral resolution.

Remote sensing is expected to become an increasingly important tool in connection with environmental mapping.

Review Questions - 01

1. Indicate what happens to the electromagnetic energy on encountering earth surface features on a diagram. Write an equation applying the principle of conservation of energy. What is the most important of these energies in terms of remote sensing and why?
2. Making use of two important observations regarding the above relationship, how can we explain the following?
3. (i) How we distinguish between different features in an image.
   (ii) The visual effect of colour.
4. What is spectral reflectance?
5. Draw graphs of typical 'spectral reflectance vs wavelength' curves for vegetation, soil and water.
6. Explain the principle used to identify vegetation from bare ground in a satellite image.
7. Explain how you can identify 'water' on images sensed on different wavelength bands.
8. Explain the terms 'spectral signatures' and 'spectral response patterns'.

9. Explain how you would map the vegetation over a region making use of the spectral signatures of vegetation.
10. What is ‘area classification’? How do you achieve this with digital satellite images?
11. What are the limitations of imagery to classification and what improvements are possible today and in the future?

Summary

We have seen the energy interactions with earth surface features and the methods used to identify image data using spectral response patterns and spectral signatures. We have also observed how temporal effects and spatial effects are used to detect changes in surface features.

Learning Outcomes

At the end of this session you will be able to briefly explain:

- the energy interactions with earth surface features, incident radiation vs absorbed, reflected and transmitted radiation from an object.
- spectral reflectance, spectral response patterns, atmospheric influences on spectral response patterns and ‘spectral signatures’.

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7. http://www.esa.int/images/04b_400.gif

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