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Energy Interactions with Atmosphere and Earth Surface

Introduction

In many respects, remote sensing can be thought of as a reading process. Using various sensors, we remotely collect data that may be analyzed to obtain information about the objects, areas or phenomena being investigated. In most cases the sensors are electromagnetic sensors either airborne or space borne for inventorying. Two basic processes involved in electromagnetic remote sensing of earth resources are Data Acquisition and Data Analysis. The elements of Data Acquisition are (a) Energy source, (b) Propagation of energy through the atmosphere, (c) Energy interactions w i t h earth surface features, (d) Airborne and/ or space borne sensors, (e) Generation of sensor data. Data analysis process involves examining the data in pictorial form or numerical form, analysis and presentation to the end users. In this article electromagnetic energy interaction in atmosphere and with earth surface are presented.

Energy Interaction in Atmosphere

Irrespective of its source, all radiation detected by remote sensors passes through some distance, or path length, of atmosphere. The path length involved can vary widely. For example, space photography results from sunlight that passes through the full thickness of the earth's atmosphere twice on its journey from source to sensor. On the other hand, an airborne thermal sensor detects energy emitted directly from objects on the earth, so a single, relatively short atmospheric path length is involved. The net effect of the atmosphere varies with these differences in path length and also varies with the magnitude of the energy signal being sensed, the atmospheric conditions present, and the wavelengths involved. Because of the varied nature of atmospheric effects, we treat this subject on a sensor-by-sensor. The atmosphere can have a profound effect on, among other things, the intensity and spectral composition of radiation available to any sensing system. These effects are caused principally through the mechanisms of atmospheric scattering and absorption.

Scattering

Atmospheric scattering is unpredictable diffusion of radiation by particles in the atmosphere. Rayleigh scatter is common when radiation interacts with atmospheric molecules and other tiny particles that are much smaller in diameter than the wavelength of the interacting radiation. The effect of Rayleigh scatter is inversely proportional to the fourth power of wavelength. Hence, there is a much stronger tendency for short wavelengths to be scattered by this scattering mechanism than long wavelengths.

A "blue" sky is a manifestation of Rayleigh scatter. In the absence of scatter, the sky would appear black. But, as s u n light interacts with the earth's atmosphere, it scatters the shorter (blue) wavelengths more dominantly than the other visible wavelengths. Consequently, we see a blue sky. At sunrise and sunset, however, the sun's rays travel through a longer atmospheric path than during mid-day. With the longer path, the scatter (and absorption) of short wavelengths is so complete that we see only the less-scattered, longer wavelengths of orange and red.

Rayleigh scatter is one of the primary cause of "haze" in imagery. Visually, haze diminishes the "crispness," on an image. In colour photography, it results in a bluish-grey cast to an image, particularly when taken from high altitude. Haze can often be eliminated, or at least minimized, in photography by introducing, in front of the camera lens, a filter that does not transmit short wavelengths.

Another type of scatter is Mie scatter, which exists when atmospheric particle diameters essentially equal the energy wavelengths being sensed. Water vapour and dust are major causes of Mie scatter. This type of scatter tends to influences longer wavelengths compared to Rayleigh scatter. Although Rayleigh scatter tends to dominate under most atmospheric conditions, Mie scatter is significant in slightly overcast ones.

A more bother some phenomenon is nonselective scatter, which comes about when the diameters of the particles causing scatter are much larger than the energy wavelengths being sensed. Water droplets, for example, cause such scatter. They commonly have a diameter in the 5 to 100 μm (mocrometer, 10 m) range and scatter all visible and -6 reflected IR wavelengths about equally. Consequently, this scattering is "nonselective" with respect to wavelength. In the visible wavelengths (Approx. 0.4 to 0.7 μm), equal quantities of blue, green, and red light are scattered, making fog and clouds appear white.

Absorption In contrast to scatter, atmospheric absorption results in the effective loss of energy to atmospheric constituents. This normally involves absorption of energy at a given wavelength. The most efficient absorbers of solar radiation in this regard are water vapour, carbon dioxide, and ozone. Because these gasses tend to absorb electromagnetic energy in specific wavelength bands, they strongly influence "where we look" spectrally with any given remote sensing system. The wavelength ranges in which the atmosphere is particularly transmissive of energy are referred to as atmospheric windows.

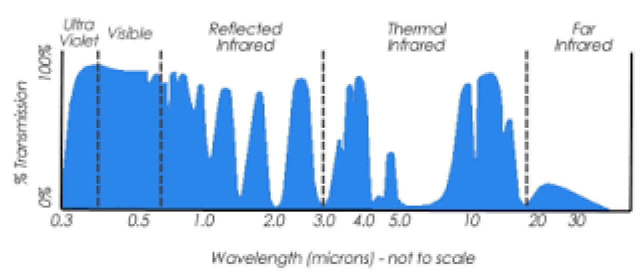
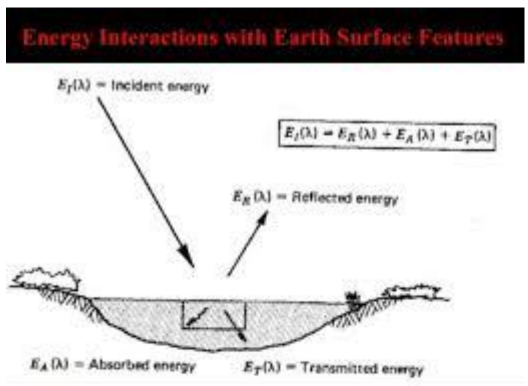


Figure shows the atmospheric absorption characteristics of electromagnetic energy. The most common sources of energy is solar energy and the energy emitted from earth. In Figure spectral regions in which the atmosphere blocks energy are shown. Remote sensing data acquisition is limited to the non blocked spectral regions, called "atmospheric windows". The spectral sensitivity range of the eye (t he "visible" range) coincides both with an atmospheric window and the peak level of energy from t he sun. Emitted "heat" energy from the earth, is sensed through the windows at 3 to 5μm and 8 to 14μm using such devices as thermal scanners. Multispectral scanners sense simultaneously through multiple, narrow wavelength ranges that can be located at various points in the visible through the thermal spectral region. Radar and passive microwave systems operate through a window in the 1 mm to 1 m region.

Energy Interaction with Earth Surface Feature

When electromagnetic energy is incident on any given earth surface feature, three fundamental energy interactions with the feature are possible. This is illustrated in Figure for an element of the volume of a water body. Various fractions of the energy incident o n the element are reflected, absorbed, and or transmitted. Applying the principle of conservation of en ergy, we can state the interrelationship between these three energy interactions as

$EI(\lambda) = ER(\lambda) + EA(\lambda) + ET(\lambda)$

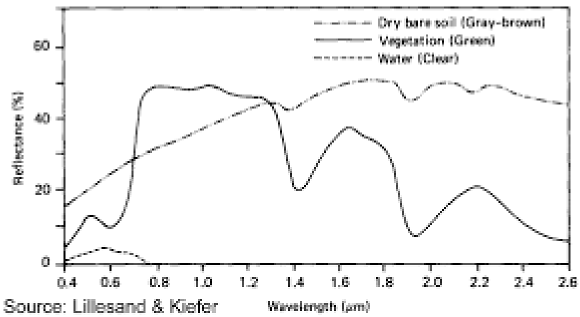


where E denotes the incident energy, E denotes the I R reflected energy, E A denotes the absorbed energy and E T denotes the transmitted energy, with all energy components being a function of wavelength λ. The above equation is an energy balance equation expressing the interrelationship between the mechanisms of reflection, absorption, and transmission.

Two points concerning this relationship should be noted. First, the proportions of energy reflected, absorbed, and transmitted will vary for different earth features, depending on their material type and condition. These differences permit us to distinguish different features on an image. Second, the wavelength dependency means that, even within a given feature type, the proportion of reflected, absorbed, and transmitted energy will vary at different wavelengths. Thus, two features may be indistinguishable in one spectral range and be very different in another wavelength band. W i t h i n t h e visible portion of the spectrum, these spectral variations result in the visual effect called colour. For example, we call objects, "blue" when they reflect highly in the blue portion of the visible spectrum, "green" when they reflect highly in the green spectral region, and so on. Thus, the eye utilizes spectral variations in the magnitude of reflected energy in the visible region to discriminate between various objects.

Spectral Reflectance of Vegetation, Soil and Water

Figure shows typical spectral reflectance curves for three basic types of earth features: Healthy green vegetation, Dry bare soil (grey-brown loam), and Clear lake water. The lines in this figure represent average reflectance curves compiled by measuring a large sample of features. Note how distinctive the curves are for each feature. In general, the configuration of these curves is an indicator of the type and condition of the features to which they apply. Although the reflectance of individual features will vary considerably above and below the average, these curves demonstrate some fundamental points concerning spectral reflectance. Fo r example, spectral reflectance curves for healthy green vegetation almost always manifest the "peakand-valley" configuration illustrated in Figure 4



Source: Lillesand & Kiefer

The valley s in the visible portion of the spectrum are dictated by the pigments in plant leaves. Chlorophyll, for example, strongly absorbs energy in the wavelength bands centered at about 0.45 and 0.65 µm. Hence, our eyes perceive healthy vegetation as green in colour because of the very high reflection of green energy. If a plant is subject to some form of stress that interrupts its normal growth and productivity, it may decrease or cease chlorophyll production. The result is less chlorophyll absorption in the blue and red bands. Often the red reflectance increases to the point that we see the plant turn yellow (combination of green and red).

Spatial and Temporal Effects

Having looked at the spectral reflectance characteristics of vegetation soil, and water, we should recognize that these broad feature types are normally spectrally separable. However, the degree of separation between types is a function o f "where we look" spectrally. For example, water and vegetation might reflect nearly equally in visible wavelengths, yet these features are almost always separable in reflective infrared wavelengths. Because spectral responses measured by remote sensors over various features often permit an assessment of the type and/or condition o f t h e features, these responses have often been referred to as spectral signatures. Spectral reflectance and spectral emittance curves (for wavelengths greater than 3.0 µm) are often referred to in this manner. The physical radiation measurements acquired over specific terrain features at various wavelengths are also often referred to as the spectral signatures for those features.

Although it is true that many earth surface features manifest very distinctive spectral reflectance and/or emittance characteristics, these characteristics result in spectral "response patterns" rather than in spectral "signatures". The reason for this is that the term signature tends to imply a pattern that is absolute and unique. This is not the case with the spectral patterns observed in the natural world. As we have seen, spectral response patterns measured by remote sensors may be quantitative but they are not absolute. They may be distinctive but they are not necessarily unique.