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Remote Sensing in Geology

Preface:

This script will concentrate on the highlights of the lectures held at Department for Geoinformatics, Palacky University, Olomouc in summer semester 2008/09. Under the spotlight, some topics will reveal the essentials in understanding multispectral satellite imagery and its application in geological and environmental aspects. It is meant to guide the reader to successful understanding and responding to a given practical problem within this scope (multispectral manipulation for geological applications). In order to stay compact, the following lines are scarce in illustrations, but supplementary "decorative" materials are available elsewhere:

http://milosmarjanovic.pbworks.com/Remote-Sensing-in-Geology

As in the finest tradition, I will spend a couple of lines to direct the reader to the script organization. Two essential parts could be segregated. Foremost part, engaging the *Introduction* and the chapters on *Remote Sensing Systems* and *Electromagnetic radiation phenomenology*, is written as an overture to the paramount reading tissue and savored in popular science style. My overwhelming infatuation is to be pardoned here and there… The second part is dealing with more practical information with examples and involves chapters on *Spectra of Earth materials*, *Image Processing* and *Applications*. More pragmatic reader should focus on the latter part in order to inspire personal idea on multispectral sensing.

Who stands on a hill, even a small one, sees more than he who stands below the hill.

Petar II Petrović Njegoš, The Mountain Wreath 1847.
(translated by Prof. Vasa Mihailovich)

Introduction

The story of Remote Sensing (RS) starts with the adventurous spirit of French photographer Nadar (Gaspard-Félix Tournachon). Pioneering many facets of photography he eventually came up with the idea for going aerial, that is shooting frames from certain altitude above the ground. He chose a floating contraption to place his massive objective mechanism and passed over Paris, back in 1858. As described above, and as all the following elaborated definitions of Remote Sensing imply, Nadar had performed the very first remote sensing data capture, inspiring many future researchers and inventors. Some interesting ideas occurred as times tensed up on the European political scene by the beginning of the XX century. One of those peculiarities certainly were mailing pigeons, equipped with tiny cameras, serving the military intelligence with the aerial snapshots of the targeted interest.

During the Great War and more notably, during the Second one, the intelligence surveillance gained momentum, starting to be essential in combat tactics, only the pigeons were swapped for robust steel successors of Brothers' Wright prototypes. Unfortunately, and unlike Nadar, pilots were not interested only in shooting photos from the air. Yet, those were times of rapid development of air-borne Remote Sensing Systems. This did not regard only the platforms, that is, aircraft design perfection. The entire associated technology has been galvanized: photographic companies innovated more sensitive color and color infrared (IR) films (for example, Kodak invented color IR film for discerning camouflage from vivid vegetation), as optics continually improved in performance including more powerful lenses, wider angled objectives and higher resolution. Thereafter, a systematic surveillance became a reality and gained significance in terms of cartographic sciences, but still under the militaristic spotlight.

Call it the dark side of human nature, but the warfares were omnipresent despite the devastation that both World Wars brought about. This time, under the code of "Cold War", delicate relations between superpowers governed a whole new era in many aspects. Cosmic Era came not a moment too soon, as the supreme reflection of those uncompromising relations. At one point, after numerous competes for placing the first satellites in the orbit or putting a man into space (not to mention "Man on the Moon" struggle) the Open Skies Policy was founded and ministered by the US government. This policy implied that anyone sufficiently interested in the research, could be provided with appropriate remote sensing data, so all the available technology could serve commercially. The scientific world was inspired to research in this brand new field, influencing back the development of RS Systems and leading us to the frontiers of RS, as we know it today. Evolving from optical, the sensors turned multispectral and hyperspectral, also involving laser and radar-based technology. Managing and processing of acquired data was also progressively perfected as new hardware and software solutions came along. Nowadays, there are incredibly versatile programs and missions, involved in different kinds of surveillance, providing scientists with tons of thematic information in many environmental aspects.

Remote Sensing is usually defined as recording of the emitted or reflected (mainly) electromagnetic energy from an object with no direct physical contact to it. Formerly regarded as a technique or a method restricted usually to cartographic or surveying purposes, Remote Sensing, with all virtues brought in sight and yet to loom, started to shape in a true scientific two-folded discipline: for one, the science of data acquisition, but also the mastery of data analysis and interpretations. It turns more demanding as novel technologies enrolled, and yet became essential and inevitable in host of environmental researches, at least in their preliminaries. Presently, it is hard to imagine any thematic mapping or spatial modeling in the sphere of Meteorology, Hydrology, Geomorphology, Geology, Mineral exploration, Forestry, Agronomy, Ecology, Urban planning and many others without Remote Sensing. Not to mention the RS vital role in tracking and monitoring various natural phenomena, from local to global scale.

I cannot help but to direct you to one of the most inspiring definitions of Remote Sensing, given by Lillesand, Kiefer and Chipman: *Remote Sensing is the science and art of obtaining information about an object, area, or phenomenon trough the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. As you read these words, you are employing remote sensing. Your eyes are acting as sensors that respond to the light reflected from this page…* This very definition has a beautiful symmetry to the body of the following chapter on Remote Sensing Systems.

Herein, remote sensing will be introduced in a scope of geological applications, as the topic of the course indicates. Colored by geological and allied environmental branches, it will turn a bit thematic, as being entirely related to the Earth’ surface and geological processes appended upon it.

Remote Sensing System

Before we acquaint with the elements of RS System, it is advisable to figure the fundamental principle, which governs data acquisition in such system (Figure 1). It is based on the fact that every single object on the Earth' surface reflects authentically under the impact of Sun radiation (or any other source), or it emits inherent portions of the energy, both due to specific physical and/or compositional attributes of its own. The energy involved is chiefly of electromagnetic origin, and the exploited spectra is usually outstretching the visible range by far. In such scenario, it is expected that different materials act very differently within the electromagnetic range and differently between each other, as well. This leaves us puzzling over solutions for capturing those differences and techniques for meaningful interpretation of their

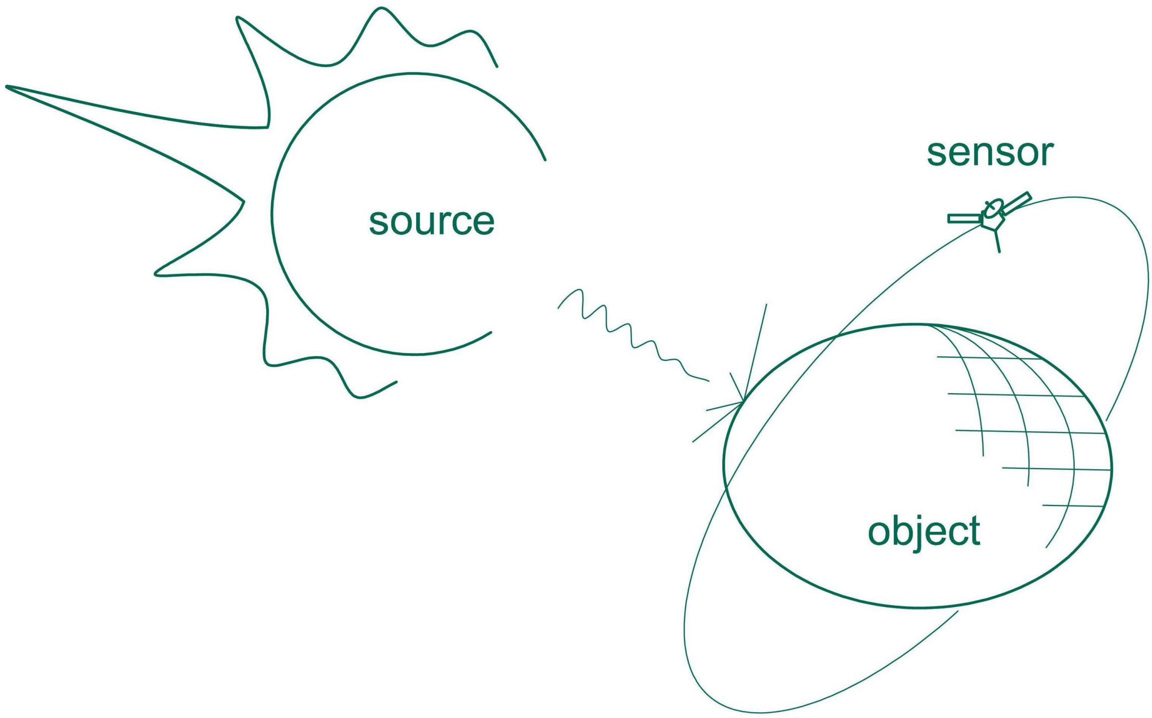

Figure 1. RS principle: the energy emitted from the source interacts with the object, sending a specific spectral response – a signal to be captured by the sensor.

distribution in specific wavelength domains. The latter will be crucial in the case of that geological problematic of ours.

The typical Remote Sensing System consists of the several elements (Figure 2): object, electromagnetic energy interaction, platform, sensor, image, analyses and data.

Object

The object of the exploration is the surface of the Earth, particularly its geological integument. Accordingly, the primary aspect or the primary feature regards geological setting, that is, lithological composition, structure and (relative) age of rock masses. Those mostly require some form of supplementary information from the ground (so-called *ground truth*), although with some advanced sensor systems, direct compositional mapping is also possible. This could be found in Hyperspectral sensing for instance, where continual, detailed spectral features are recorded and readily interpreted, if target rock spectra are familiar and rather discernible from non-target portions of rock. In addition, geomorphological properties need to be analyzed in detail, since they seem to be the most informative for depicting geological entities. After all, geomorphological features are driven by the geological background's response to the external and internal conditions and processes, so the bond between geomorphological and geological features is reasonably firm.

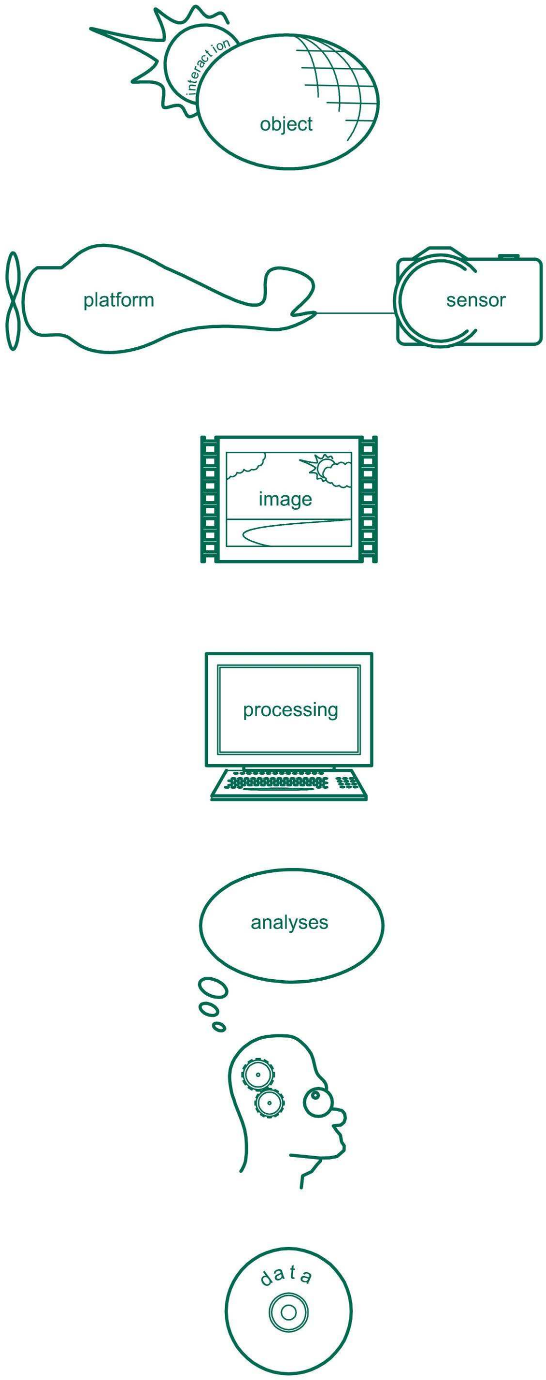

Figure 2. Scheme of RS System

Electromagnetic energy

Electromagnetic energy is involved in the system as both, the promoter of the source-object interaction and its recordable outcome. It is induced in the source and radiated out in the form of electromagnetic waves, which react with the object, finally captured while being bounced off toward the sensor. On this journey they initially face the medium between the source and the object, presented by vacuum space (in satellite systems) and more importantly, the atmosphere, were different types of dissipation take place, "contaminating" the initial beams of energy up to some extent. As they reach the surface, an interaction occurs with the Earth materials. Electromagnetic waves are partly consumed and slightly altered. In which fashion and to which extent mainly depends on the physical and chemical properties of the material at hand. In turn, appropriate portion is being reflected back and recorded. The range of its spectra in terms of RS is usually restricted to the visible, infra red and microwave domain, but more on this in the following chapter.

Platform

For the systematic and accurate recording, an appropriate platform is necessary. The type of platform is dictated by the complexity of the sensor mechanism. In return, the platform affects the resolution and some spectral aspects of the sensor at hand. Technological development provided a host of solutions for air-borne and satellite systems. Systematic surveillance is especially typical for surveying satellites. They represent the systems that orbit the Earth at specific heights (where solar wind radiation has been cleared out within radiation-free zone – a curiosity of gordian features of the global magnetic field and electric discharge of the atmosphere combined), with corresponding frequency of overpasses. Due to the complexity of this topic, we will consider this description sufficient enough.

Sensor

Sensors had an exciting and creative development from optical to microwave systems. They will be regarded in this direction, that is, according to their technological solutions, although they could be classified by many other criteria. Just for example, they could be classified by their activity, as passive sensors – recording the reflected energy, generated by another source, and active ones – recording the signal they produce on their own (behaving as a source and a sensor at the same time).

Chronologically, photo-optical systems came about first, implying optical constructions for conducting the light to a photosensitive medium and finally to a hardcopy (just as classic photography implies). Simple as they were (with constructional resemblance to a human eye), they had distressing restriction to a visible, conceivably ultra violet + visible + near infrared domains (with wavelengths 0,3 – 2,5 μm), followed by all the disadvantages of hardcopies over digital imprints. Moreover, mosaicing (merging adjacent frames into a larger scene) is also quite troublesome, since the reflected energy of usually inconsistent source (such the Sun is) varies while frames are being captured. It so happens that between two adjacent frames, atmospheric effects (acting on behalf of the presence of water vapor, pollutant particles, changes in air density, motion of the air masses, precipitation etc.) or the relative position of the sun, or its inconsistent radiation, impose differences in the frame illumination, causing tone and color mismatches. On the other hand, resolution is fair, scenery is readily comprehensible and stereo effect is easily achievable (simple stereo principle, once again resembling to human eyes, is based on the fact that an object imaged from two adjacent positions, will appear three-dimensionally). The latter knows to be quite desirable in structural analysis, since 3D impression enrich spatial comprehension. The ultimate curiosity in going stereo could be found in some space programs such as STEREO (NASA's Solar TErrestrial Relations Observatory with twin satellites), which uses this effect to track the solar flares: their scale and speed as they propagate from Sun toward the Earth.

Advances came along in electro-optical sensors by using a wider spectral range and digital outputs. Namely, the signal recorded by sensor is converted to electrical impulse, leaving a handful of alternatives for automated displaying and transmitting the image (convenient for satellite systems). In turn, different types of cameras occurred (implying cathode technology) and succeeded by more and more complex scanner systems. The latter involved Charged Couple Devices (CCD) technology, resolved in several manners: whiskbroom scanners (optical-mechanical systems – CCD are compacted in detector while rotating or oscillating mirrors and lenses deflect the signal toward it, providing linear swaps of the ground area), pushbroom scanners (CCD are aligned in detector, providing continual swaps of the ground area) and digital cameras (CCD are arrayed, capturing the whole scene per ground area simultaneously). The most significant innovation in those sensors is that they turned multispectral, that is, they entailed detecting of spectral domains far beyond visible, by separating the signal spectra trough the systems of crystal prisms and transforming this decomposed signal by proper transmitters per each wavelength domain. For the most, Thermal Infrared (TIR) channels provided intriguing insight into the compositional properties of the Earth materials, since this spectral region is restricted to the emitting energy (the black body emission). Naturally, the atmosphere restricts certain bands and discontinues this spectral range (with wavelengths 0,4 – 15 μm), but more on this in the chapter on Electromagnetic radiation phenomenology. A Hyperspectral sensor system provided near-continual sensing for wide spectral range, utilizing extremely high spectral resolution for detailed mineral mapping, vegetation tracking and so on.

Eventually, microwave systems brought in even further extended detection. Those systems are mainly active, meaning that they supply the initial signal and capture its echo, afterwards. Beside the unique spectral range, they have a consistent (artificial) source with little or no variation in energy emission, making the image processing more feasible. Those detectors are also called RADARs (RAdio Detection And Ranging), alluding to the radio-wave range of electromagnetic spectra. However, their principal domain is within the microwave interval (with wavelengths 1 mm – 1 m). There are several technological ramifications, beginning with Side Looking Radar (SLR), which include Real Aperture Radar (RAR) and Synthetic Aperture Radar (SAR). Other types are including LIDAR (LIght Detection And Ranging) usually utilized by polarized emitters, so extremely precise in determining spatial disposition of the echo. Furthermore, interferometry method (InSAR), analogical to stereo imaging principle, benefits in even higher accuracy. What they all have in common is their penetrability. With beams that are (due to a large wavelength) discarding the majority of atmospheric obstacles, some vegetation, even penetrating loose topsoil to a certain extent, they found their purpose in accurate topographic modeling.

Another important feature that we need to become conversant with is sensor resolution. It regards several aspects, so we distinguish those as follows: spatial, spectral, radiometric and temporal. Spatial resolution determines the proportion between sizes of a ground area versus its projected analogue in the sensor. In digital imagery, the pixel size indicates how coarse resolution tends to be, as explained in the following paragraph. Spectral resolution is defined by a range of spectra in which the sensor's band operates – smaller the bandwidth, finer the resolution and vice versa. Radiometric resolution is an actual sensitivity to radiation change. Sensors with finer radiometric resolution have a higher sensitivity. Temporal resolution is simply expressed as repetitiveness or a frequency of overpasses. In addition, microwave systems have somewhat specific aspects on resolution, such as azimuth and range resolution (for example, finer azimuth resolution is found in SAR due to the amplification of the signal in antenna).

Image

The image could be considered as the outcome of any discussed RS System, although it officially refers only to raster or digital sets, while the hardcopies from optical systems are preferably denoted as photographs or contact-copies. Since we will be focused on multispectral systems, where raster sets happened to be the final product, the term image will be considered solely as a raster.

Let us remind ourselves that raster could be illustrated as a 2D matrix of cells, so called picture elements or pixels, aligned in rows and columns. They are replicating the ground scene, so that every unit area or a sub-scene on the ground corresponds to a specific pixel in the matrix. Their size and number define the image spatial resolution – the bigger the size (or smaller the number), coarser the resolution. Pixels are also carrying the information on the reflectance value per each ground sub-scene. That value is known as tone/color Digital Number (DN) and represents the average spectral response of the ground entities captured by one pixel. The value is expressed numerically, according to a default color model, so we could picture a raster image as a matrix of integer numbers of certain range. Grayscale images (8-bit data) for instance, range in DN values from 0 for black (with the lowest reflectance) to 255 for white pixels (with the highest reflectance). These monochromatic grayscales happen to be the most widespread forms of raw multispectral data, where each band represents a separate grayscale or tone image. Building a color composite of the user's choice comes into play through some color model.

Human visual comprehension of colors is a bit intriguing. Darwinists would agree that our eyes could be listed among the most complex ones, trained by the evolution to focus on specific, apparently the most convenient parts of the spectra (Figure 3: the peak of the Sun radiation fits the visible range, serving our vision with the strongest signal). Yet, the present-day detectors are outstretching our sensible spectra, leaving us wondering over proper fashions to represent something that is ostensibly invisible and incomprehensible in terms of colors. There are several color models helping us to balance between our limited eye-perception and variety of wavelengths available with advanced sensors. The idea is to present the sensor's recordings from those invisible domains by a color combination, which will represent recorded information in the best fashion. RGB (Red Green Blue) and IHS (Intensity Hue Saturation) are the most significant color models. The former being based on the fact that every single color nuance could be expressed as a blend of three basic colors (red, green and blue), represents an orthogonal coordinate system or a color space (cubic color space) with the axis ranging from 0 to 255, so that any color could be coded via three RGB coordinates. The latter is closer to the physical phenomenology of color, having three parameters (hue, intensity and saturation) to determine any color variation. Hue corresponds to the dominant wavelength, intensity to brightness or scene luminance and saturation for the purity of spectra (in which proportion the white, light that is the white color, obscures the dominant wavelength). It is also presented by color space, usually conical rather than cylindrical.

Finally, image resolution topic parallels the foregoing discussion on spatial sensor resolution so there will be no further notes over this.

Raw digital image is feasible for further processing, since conveniently structured for more or less complex algebraic manipulations within the matrix (functioning, ratioing, filtering, transforming, classifying). Furthermore, its tone/color quantified information (DN) is not fix, but subdued to various operations, governed by user ideas on spectral relations of materials captured by the image.

Analyses and interpretation

After being served with the appropriate image, one can embark upon its analysis and interpretation. In the light of multispectral images, with few exceptions, stereoscopy is not quite common, so the mainstream on analysis and interpretation will be focused on dealing with single satellite images and their processing. Since the entire chapter will be dedicated to image processing and another one to geological scope of image interpretation, only pertinent matters will be pointed in the following paragraphs.

Due to the implied principle, analysis could be essentially two-folded: visual and automated (formal), with their hybrid in addition. Visual is based on the perception, knowledge and experience of the user, that is, his ability to resolve features of interest by his subjective logical virtues. This is reasonable in terms of geo-applied remote sensing, since observation plays an important role in all geological sciences. On the other hand, automated analysis employs calculation or relation over pixels, suggesting similarities or dissimilarities of their pattern (grouping, lineation and other spatial relations). What they both have in common is that the images are usually prepared (pre-processed and enhanced) in a suitable form to ease the effort of the analysis, yet the processing is continued in the automated analysis to a further extent. Moreover, they both exhibit some shortcomings. In turn, visual approach is limited by the perception and the experience of the user, while automated analysis is not entirely reliable when it comes to the meaningful and plausible explanation of the anomalies or some specific patterns. This is precisely why their hybrid combination could meet all the requirements, by inheriting merits and discarding the drawbacks in both.

Analysis is usually separated from interpretation, leaving the user to piece together the meanings of the patterns obtained by single calculation, or obtained in several inter-stages of analysis (image processing). On the contrary, the process is sometimes continual, with no separation between analysis and interpretation. The latter is confined to the visual approach, where the meaning is instantaneously assigned as the criteria for distinguishing some feature appears (for instance, the interpreter spots a drainage pattern typical for fine-grained sediments and assigns this lithological explanation to a specific area, encircled by that diagnostic pattern).

Data

The result of the entire process of acquisition, preparing, processing and finally interpreting the image is data, exposed to the user or the group of users usually for their preliminary glimpse into the given problematic. It is usually embodied as a thematic map of some property or phenomenon distribution. At times, the RS approach serves no more but to confirm or decline the expectations of target property/phenomenon, securing decision-making for incoming, detailed geological exploration, but every once in awhile, it leads to the staggering and rather intriguing findings.

Hence, to become useful information, RS data needs to retrieve something new into the sight, be it simply a new level of exploration (synoptic view of the area of interest at different, larger scale reveals better regional relations between geological entities) or a new finding envisaged by the spectral perspicacity of the supreme sensor technology. Moreover, data coverage is complete, leaving no room for results extrapolation to the portions which were not directly prospected. Since the information is quantitatively continual and properly structured (as raster set), it is feasible for implementation into Geographic Information System (GIS), if adequately geo-referenced and databased. In effect, the output of the RS System becomes the input of the GIS, so further calculations and modeling could take place. Once integrated in GIS analyses, RS data could serve in surpluses of different researches.

Electromagnetic radiation phenomenology

Before we cope with the spectral features of Earth materials, let us recall the basic Physical background of the nature of electromagnetic radiation and its interaction with the matter.

Basic principles

This phenomenon was studied in depth from the 19th century on. Herewith, the basic principles were determined and included postulates on the dual nature of electromagnetic radiation theory: the wave-based and corpuscular principle. Namely, radiated energy propagates in sinusoidal wavelike motion, with electric and magnetic fields oscillating perpendicularly to each other, while being orthogonal to the wave propagation direction. However, it had been suggested that it also contains energetic portions, not just the energetic fields. As revealed in quantum theory, those indivisible portions, called photons or quanta, are behaving and interacting as massless elementary particles and expressing wavelike nature simultaneously. For illustration, imagine the thermonuclear reaction in the Sun's core, producing electromagnetic energy to heat and illuminate our planet. It kicks off with the wavelike propagation of the energy, repeatedly performed and slightly changed (absorbed and reemitted) after every single interaction to come. Since exhibiting particulate nature, wherein the photons are interacting with compounds of the Sun's inner tissue, the energy will be transmitted very slowly from one particle to another (like escaping the immense labyrinth). The journey to the Sun's surface could take thousands of years, but once emerged, facing the open space (vacuum space with no or extremely sparse matter), the photons would rush to reach the Earth's surface in about 8 s. So, the beam of light that we see, came as the result of the gamma ray photon borne in the Sun's core thermonuclear reactor, shredded in many interactions to a spectrally diverse visible light assemblage, lower in energy than original gamma ray (again because of the interactions) and taking almost a million years (+8 s) to arrive.

This is, by all means, a complex theory, even overextended with the influence of the Einstein's relativistic approach. Therefore, we will concentrate only on a couple of basic equations and models in order to close up to our primary objective of understanding material interaction with visible light and beyond. For one, the wavelike behavior expressed by following law:

$c = \lambda \cdot v$ .... [1]

(where c stands for velocity, λ for wavelength and v for the frequency of oscillations) suggests that in particular medium the velocity of electromagnetic propagation is constant, that is, the frequency is inverse versus wavelength. Only the frequency stands for the inherent property of wave, invariable to the nature of the medium at hand, while conversely, wavelength and velocity varies from one medium to another. Since it is going to become the most referred to herein mark the parameter of wavelength – λ (given in µm or nm), which is defined by the distance after which the oscillations is entirely repeated.

As for the corpuscular share of electromagnetic nature, the energy of a photon could be written as:

$E = H \cdot v$ .... [2]

(where E stands for the energy, H for empirical value called Plank's constant) implying that emitted energy is also constant in a medium and that higher frequency (or shorter wavelengths) entails a higher energy (Figure 3: note the shift toward the shorter wavelengths as the source becomes higher in energy).

Furthermore, one of the central models in comprehension of the electromagnetic energy emission is the blackbody model. As you might recall, it is an idealized body, which absorbs all incident energy continually, at all wavelengths. Yet, the real bodies are not performing such absorbance since having a discrete wavelength intervals absorbed just up to a certain share instead (Figure 3). So all real bodies (at the temperature above the absolute zero) are radiating certain portions of energy, but the intensity and the spectral distribution of that radiation depends on the compositional and physical properties of the particular body.

Another important rule to remember relates the phenomena of absorption and emission of the energy. It is called The Kirchoff's law and states that the amount of the energy that the body absorbs equals the amount of emitted energy. This means that good absorbers are simultaneously

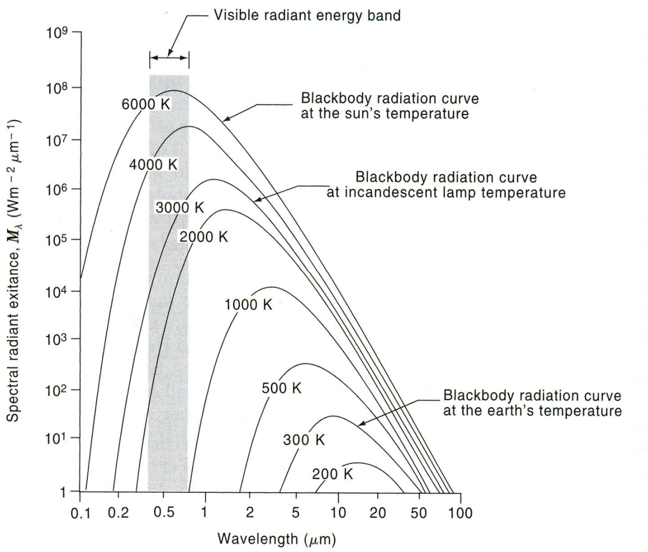

Figure 3. Spectral spans of black body radiations at different t° (Lillesand *et al.* 2004)

good emitters and poor reflectors and transmitters of the electromagnetic energy. In plain English, a material which expresses a high absorption at specific wavelength, turns to be a poor in reflection for that wavelength (Figure 4).

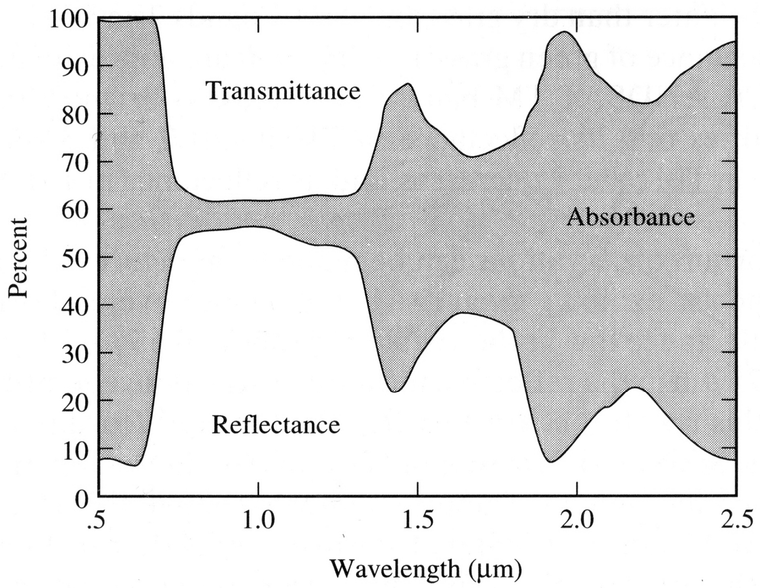

Figure 4. Kirchoff's law depicted in spectral relations of reflectance, transmittance and absorbance (note how firs two are symmetrical and inverse to absorbance, meaning that high reflectance means low absorbance, and high transmittance) (Vincent 1997)

Spectra

Spectra of electromagnetic energy is an arrangement in accordance to the frequency/wavelength or energy, displayed usually in descending order from higher to lower frequencies or energies, that is, ascending from shorter to longer wavelengths. Waves are usually classified by one of those properties, whereas each interval represents a specific type of electromagnetic energy. The span ranges from cosmic rays, to radiowaves, trough domains of γ-rays, x-rays, ultraviolet light, visible light, infrared domain and microwaves. All of those are being produced by specific processes during the energy-matter interaction at atomic or inter-atomic level. This interaction also determines whether those rays are suitable for specific RS Systems. For example, the optical range (visible + IR) domain is the most exploited so far, since most suitable for the sensors at hand and most informative on earth materials. Let us now put a shy glimpse upon basic specifications of those particular domains.

Cosmic rays are laying on top of all domains by their energy, but they are not exactly expressing wavelike behavior. They could rather be pictured as showers of individual particles (not massless photons) incoming from the Sun, stars, and other peculiar objects from distant quarters of the universe. Herein, they are only enlisted as a digression, due to their energetic relation to other spectral domains, but basically they are out of the spectra, as far Remote Sensing is concerned. The most recent curiosity I have dug out on cosmic ray interaction within the atmosphere regards the very essence of lightning strike behavior. Lately, believes are piling up that cosmic rays actually conduct the charged electricity present in the clouds of the lower atmosphere straight to the ground. As they pass the air masses they are being partly absorbed, but some particles are perpetually penetrating all the way down to the very surface of the Earth and beyond. Those particles galvanize the air so the charge could find its authentic and picturesque path from the cloud to the ground. However, take this approach cautiously, since it is yet solely hypothetical one.

As suggested by the equation [2], shorter wavelengths entail higher energy, so our next stop are γ-rays. They are generated as changes in proton or neutron states alters within the atomic nucleus, yielding information only about the nucleus of an atom, likewise the above mentioned cosmic rays. Occupying the wavelengths shorter than 0,0001 µm, γ-rays are not quite penetrable, since mostly absorbed by the atmosphere, so not exactly our RS cup of tea.

X-rays are the second shortest domain, ranging from 0,0001 to 0,01 µm, although those are arbitrary outlines, since the overlap with gamma domain is also an option. What vitally differs them from the former domain is their origin. Unlike gamma, they are emitted or absorbed by the inner-shell electrons in the atom's structure. They have slightly higher penetration, so they are considered in some spectrometry systems with low-pass borne sensors, for depicting natural radiation of the ground masses for instance.

UV domain range over 0,01-0,4 µm span, and originates as the electronic interactions take place in the outer atomic shells. Penetrability is even more significant, but still confined to air-born low-passing sensors.

Visible range includes so-called white light spectra, a spectral interference of wavelengths at the interval 0,4-0,7 µm. It also originates from the electronic transmission processes within outer shells of the atom. It is certainly the most exploited spectral segment, primarily due to the atmospheric spectral absorbance and penetrability which is reaching its very peak in this range (Figure 3), and perhaps because our own vision happens to be confined to this range, so the analogy is replicated to the majority of the sensors (branch of optical sensors). Widely accepted sub-classification of this range includes spectra of rainbow color scale, which indeed appears as beam of white light gets to be analyzed trough a crystal prism or rain drop for example. In turn, this subset of violet, blue, green, yellow, orange and red color tends to be simplified with basic bands/colors (Blue: 0,4-0,5 µm, Green: 0,5-0,6 µm and Red: 0,6-0,7 µm).

Infrared range is a vast one, with 0,7 µm outset all the way down to 1000,0 µm or 1 mm. In effect its phenomenology is somewhat ambiguous, which particularly matters to our aspect of dealing with this portion of spectra. Instead of discussing the arbitrarily leveled classifications (near, short wave, mid, and far infrared) we will separate two originally different types of radiation: reflective and thermal one. Reflective infrared domain encompasses the 0,7-3,0 (4,0) µm interval, and still propagates on behalf of the inner-atomic, that is, outer-shell electrons interactions. Most importantly for the RS, this domain is still propelled by the Sun's activity and shares the information which is an actual reflective response to the source radiation. Moreover, up to this point all radiation yielded inner-atomic information, which means that primarily elementary compositional data could be extracted. On the other hand, thermal range (3,0-1000,0 µm) yields inter-atomic composition, since the interactions which produce these kinds of wavelengths are embodied in inter-atomic relations, the rotational and vibrational motions in molecular or crystal assemblages in particular. This is useful in geological research for extracting information on bulk mineralogy (which is a bit tricky though, since Sun's radiation obscures the infrared pure thermal radiation), and if the sensor possesses higher spectral resolution even the rock temperature estimations are available. This justifies the nickname forged for this domain.

Microwave segment is an even wider range (1 mm-10 m) and it is usually confined to active sensor systems (involves artificial source), although some natural bodies do emit weak signals in this domain (our Sun for instance). Photon concept is not that illustrative in this case, but it is still valid, as shown in interactions of microwaves with different media. For RS they are considerably important when high penetrability is required. Throughout the entire range atmospheric noises are negligible, most of the vegetation cover could be avoided, even the topsoil to a certain extent, so the applicability is versatile. Hence, if you need to render a humid, cloudy area with dense vegetation cover you might think about microwaves. You may also think about them as your pop-corn cracks, impinged by 12,5 cm wavelength (the wavelength that violates water molecules, resonates with them, causing thermal upraise in everything that contains aqua) in the microwave oven.

Radiowaves are more technical reference to the spectral domain which extends 1 m in wavelength, but also includes those overlaps with microwave region which are being used in television or radio techniques, even bands of mobile and other communicational systems. For RS Systems they are not especially interesting nor used in terms other than to communicate with satellite-born sensor.

Effects

Now it is necessary to get familiar with the effects that a signal copes with on its journey (Figure 1). First we need to distinguish between the reflected signal and directly emitted one (thermal infrared range). Unlike the former, emitted signal passes through the medium only once, before it gets captured by the sensor. In effect, the signal is purer and avoids some of the effects hereafter to be discussed (in the atmosphere and on ground). This milestone is critical for some processing approaches and estimations of thermal properties of rocks and soils. However, the other, reflected kind of the pathway is in dominion, so we could stick more closely to that for a while.

If we line up the basic effects we would be dealing with the following list: scattering, absorption, emission, reflection and transmission and in addition almost all of these could be of atmospheric or terrestrial origin. So let us start first with the atmospheric scattering in a nutshell…

Scattering happens as incident radiation interplays with the particles in the air and disperse the energy around them in some fashion. It depends on the particle size, that is, the relation of their size to the wavelength at hand. For instance shorter wavelengths will be of greater contribution for scattering over gaseous molecules in the upper atmosphere, which explains the blue skies effect (blue, as the shortest wavelength interval in visible light, is being scattered). This rule generally stands for any particle size, so noise which causes haze in the images declines toward the longer λ. This specific noise is called the path radiance (Figure 5) and obscures the visible blue and UV end of the spectrum. Plunging down the lower atmosphere we face the increase in particle size, so that dust aerosols even exceed λ of visible light, meaning that path radiance shifts toward longer waves of the spectrum.

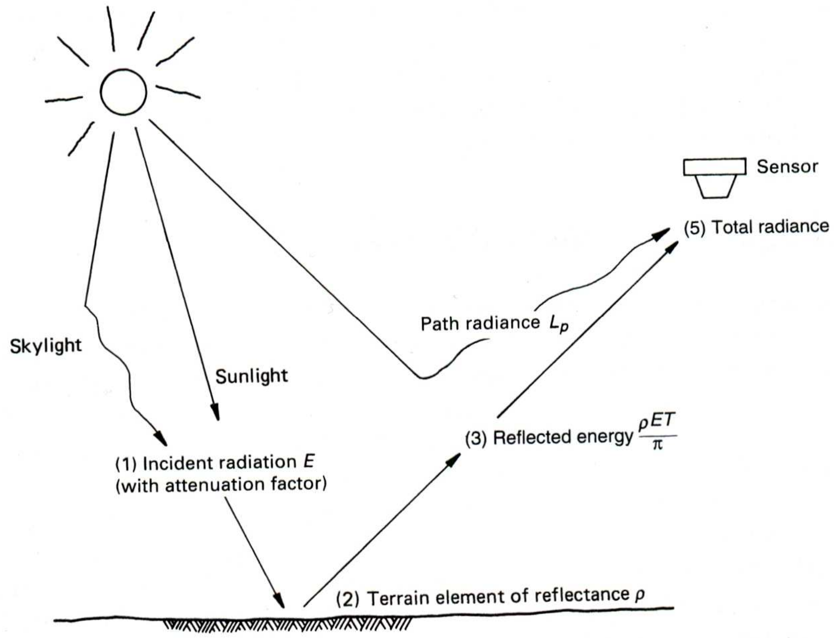

Figure 5. Scheme of atmospheric and ground effects (Lillesand *et al.* 2004)

Absorption is another important effect in the atmosphere and it actually governs which portions of the spectrum are available for sensing. Namely, certain wavelengths, bearing sufficient energy to overtop the thresholds and cause energetic changes on inner-atomic level, are being absorbed by different gaseous components such as water vapor, O_2, O_3, CO_2 and so forth (Figure 6). This discontinues the spectra leaving some domains clear and others opaque and inaccessible for sensing. Those clearances are colloquially named atmospheric windows and one of the most important windows are placed within the visible range and also TIR range at 8,0-14,0 μm. The latter is curious for the presence of high ozone absorption band right in the middle of the interval (around 10 μm), going in favor of aerial over satellite sensing.

Atmospheric emission appears due to the thermal properties of Earth's gaseous shell. As such it emits discrete bands of the spectra according to the chemical composition. It supposes to be troublesome, since one could expect magnified haze in the images, as it superimposes on path radiance. Luckily, poor emission also implies poor emission (Kirchoff's law), so atmospheric windows (poor in absorption) are spared of significant emission noise.

Down on ground more complicated interaction takes place and it has to do with reflection, absorption, transmission and emission acting vis-à-vis. As incident signal interacts with ground materials it yields information on structural features and chemical composition.

Reflection in natural conditions struggles between two extremes, two idealistic models. The first is specular surface model where single incident beam bounces-off a mirror-flat surface giving a single, symmetrical reflected beam (reflection angle matches the incident angle and lies in the same plane). The second model is called Lambertian surface model, where an incident beam gets resolved evenly in all directions off the rough surface (irrespectively to incident angle). Since idealized those models are used in appropriate calculations and estimations, but it is important to remember that true behavior lies somewhere in between. This especially regards the

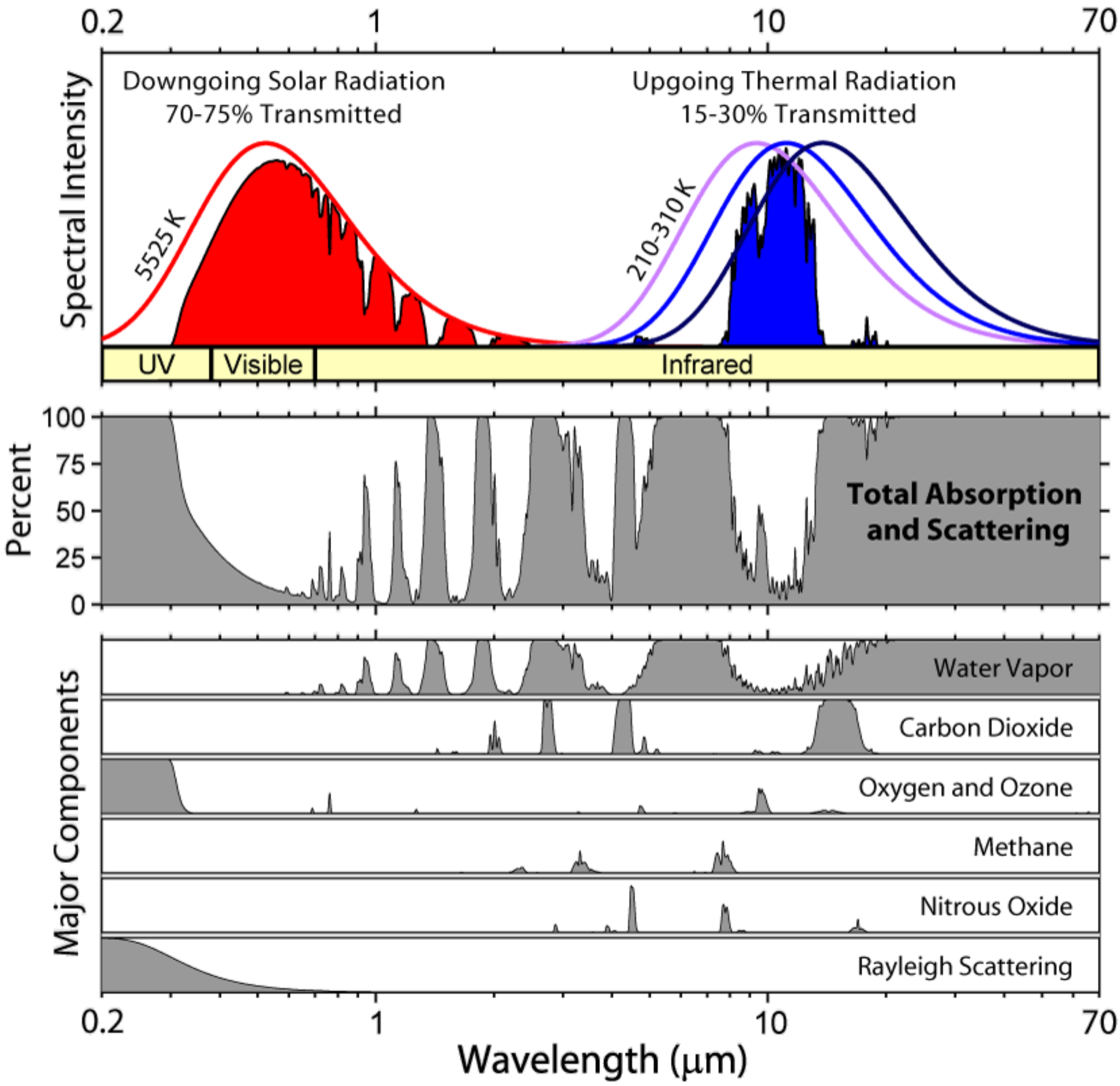

Figure 6. Atmospheric absorption bands in relation to corresponding gaseous components

incident angle in geometrically different RS Systems (oblique geometry in SLR and sub-vertical in LIDAR or passive sensor systems) and influences the image interpretation.

Absorption and transmission are also selective mechanisms, meaning that they work in favor of one wavelength over another in a specific medium, since the medium governs which levels of energy are sufficient to excite the interaction on atomic level, as already discussed.

Emission from the ground relates to the thermal properties of the bedrock and provides precious information on medium interior.

Spectral curve & parameters

One last stop before we clinch with the spectral behavior of ground materials more explicitly. The first term to deal with would be the spectral curve – a diagram of the reflection or absorption parameters over different wavelengths. In other words, it is a spectral response to the radiation directed upon an object or emanated from within. Radiation is commonly given by transmittance, absorbance or reflectance (Figure 4) as fractions of incident versus recorded energy, measured by spectrometers. This involves sampling and measuring on the ground in order to obtain spectral response. This spectrometric response is certainly different from what could be recorded in RS sensor (when all atmospheric and ground effects come into play), but extracted curve suggests general spectral behavior of particular material and therefore, should be used to configure multispectral investigation. Hence, for planning of any thematic RS endeavor (choosing the sensor with optimal band coverage for meaningful implementation to the problem), it is essential to analyze target's spectral characteristics first. These analyses comprise of recognizing the most authentic patterns in the spectral curve's behavior (absorption/reflection maxima and minima and wavelengths at which they occur), putting the target material under the spotlight.