THERMAL REMOTE SENSING: CONCEPTS, ISSUES AND APPLICATIONS

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ABSTRACT

In the last few decades remote sensing has reached from an experimental to an operational level. The increase in the number of earth observation satellites, the advancement in tools and processing techniques, and the use of data for new applications has been phenomenal. However, the major part of the efforts were directed in the past towards the use of optical data and now also to the use of microwave data. The available literature underlines the fact that the use of data acquired in the thermal infrared region has been relatively limited within the scientific and application community. The limited use of thermal data is linked to several facts such as the limitation of the sensor capabilities, the nature of data itself, and the reluctance of many to explore the potentials of thermal remote sensing. This paper deals with the concepts and issues of thermal remote sensing and presents a variety of applications where thermal data finds its way. The benefits and limitations of thermal data are discussed and the potential of thermal remote sensing, specially in light of future high resolution satellites, is highlighted. The paper concludes with the author's views on the importance of these aspects specially in the standard remote sensing educational programmes.

1 INTRODUCTION

Thermal remote sensing is the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. In thermal remote sensing we measure the radiations 'emitted' from the surface of the target, as opposed to optical remote sensing where we measure the radiations 'reflected' by the target under consideration. Useful reviews on thermal remote sensing are given by Kahle (1980), Sabins (1996) and Gupta (1991)

It is a well known fact that all natural targets reflect as well as emit radiations. In the TIR region of the EM spectrum, the radiations emitted by the earth due to its thermal state are far more intense than the solar reflected radiations and therefore, sensors operating in this wavelength region primarily detect thermal radiative properties of the ground material. However, as also discussed later in this article, very high temperature bodies also emit substantial radiations at shorter wavelengths. As thermal remote sensing deals with the measurement of emitted radiations, for high temperature phenomenon, the realm of thermal remote sensing broadens to encompass not only the TIR but also the short wave infrared (SWIR), near infrared (NIR) and in extreme cases even the visible region of the EM spectrum.

Thermal remote sensing, in principle, is different from remote sensing in the optical and microwave region. In practice, thermal data prove to be complementary to other remote sensing data. Thus, though still not fully explored, thermal remote sensing reserves potentials for a variety of applications. The next sections discuss the main concepts and issues of thermal remote sensing and continue to present a brief overview of the application of thermal data. The article concludes with the advantages and limitations of thermal remote sensing and the need for including this topic in remote sensing educational programmes.

2 CONCEPTS

In thermal remote sensing, radiations emitted by ground objects are measured for temperature estimation. These measurements give the radiant temperature of a body which depends on two factors - kinetic temperature and emissivity. Figure 1 presents the various factors affecting the radiant temperature and these are further discussed in subsection 2.2. Subsection 2.3 presents the concept and measurement of radiant temperature which is the basis ef estimating radiant temperature from thermal remote sensing data. However, before presenting these concepts, subsection 2.1 briefly discusses the wavelength ranges which are of interest for thermal remote sensing.

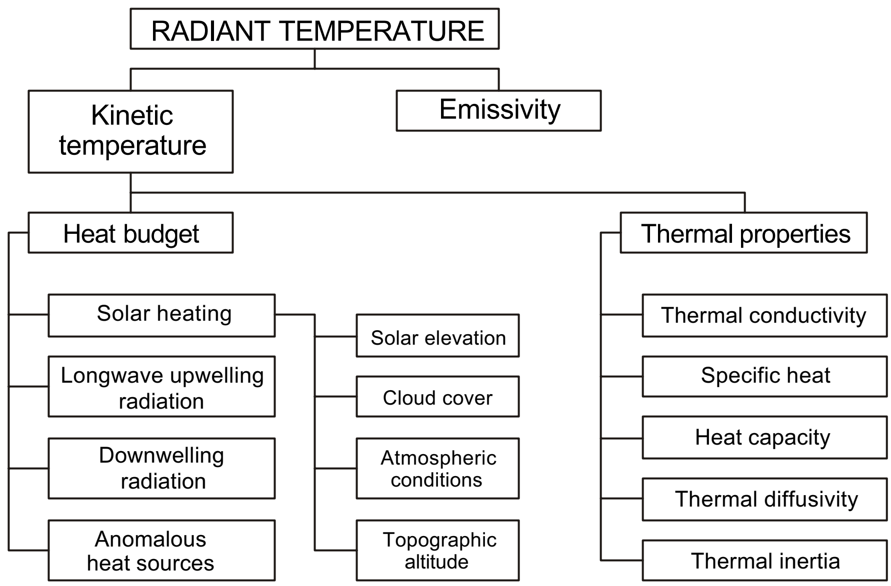

Figure 1. Factors controlling radiant temperature

2.1 Wavelength / Spectral Range

The infrared portion of the electromagnetic spectrum is usually considered to be from 0.7 to 1,000 µm. Within this infrared portion, there are various nomenclatures and little consensus among various groups to define the sub-boundaries. In terrestrial remote sensing the region of 3 to 35 µm is popularly called thermal-infrared. As in all other remote sensing missions, data acquisitions are made only in regions of least spectral absorption known as the atmospheric windows. Within the thermal infrared an excellent atmospheric window lies between 8-14 µm wavelength. Poorer windows lie in 3-5 µm and 17-25 µm. Interpretation of the data in 3-5 µm is complicated due to overlap with solar reflection in day imagery and 17-25 µm region is still not well investigated. Thus 8-14 µm region has been of greatest interest for thermal remote sensing.

2.2 Spectral Emissivity and Kinetic Temperature

Thermal remote sensing exploits the fact that everything above absolute zero (0 K or -273.15 °C or –459 °F) emits radiation in the infrared range of the electromagnetic spectrum. How much energy is radiated, and at which wavelengths, depends on the *emissivity* of the surface and on its *kinetic temperature*. Emissivity is the emitting ability of a real material compared to that of a black body (see 2.2.1), and is a spectral property that varies with composition of material and geometric configuration of the surface. Emissivity denoted by epsilon (ε) is a ratio and varies between 0 and 1. For most natural materials, it ranges between 0.7 and 0.95. Kinetic temperature is the surface temperature of a body/ground and is a measure of the amount of heat energy contained in it (see 2.2.2) . It is measured in different units, such as in Kelvin (K); degrees Centigrade (°C); degrees Fahrenheit (°F).

2.2.1 Black body is a theoretical object that absorbs and then emits all incident energy at all wavelengths. This means that the emissivity of such an object is by definition 1. Needless to say, such an object is only imaginary and no natural substance is an ideal black body.

2.2.2 Factors Affecting the Kinetic Temperature can be categorised in two broad groups - heat energy budget and thermal properties of the materials (figure 1). Heat energy budget includes factors such as solar heating, longwave upwelling and downwelling radiations, heat transfer at the earth-atmosphere interface and active thermal sources such as fires, volcanoes etc. Thermal properties of material include factors such as thermal conductivity, specific heat, density, heat capacity, thermal diffusivity and thermal inertia of the material. An excellent explanation of these factors is given by Kahle (1980).

2.3 Radiant Temperature

The radiant temperature (T_R) is the actual temperature obtained in a remote sensing measurement and, as mentioned earlier, depends on actual or kinetic temperature (T_K) of the body and the its emissivity (ε). The total radiations emitted by non black body (natural surfaces) is given by

$$W = \varepsilon \cdot \sigma \cdot T_K^{\,4} = \sigma \cdot T_R^{\,4} \qquad (1)$$

where σ is the Stefan-Boltzmann's constant. This defines the relation between the radiant temperature and kinetic temperature of a body as

$$T_R = \varepsilon^{1/4} \cdot T_K \qquad (2)$$

From the above equation, and the knowledge that all natural materials are non-black bodies with emissivity less than one, it is clear that the radiant temperature (temperature estimated by remote sensing data) is always less than the actual surface temperature of the body by a factor $\varepsilon^{1/4}$.

The total amount of radiations emitted by a body can also be estimated using Planck' equation which gives:

$$W_\lambda = \frac{2\pi \cdot h \cdot c^2}{\lambda^5} \cdot \left(\frac{1}{e^{h \cdot c / \lambda \cdot k \cdot T} - 1} \right) \cdot \varepsilon_\lambda \qquad (3)$$

where W_λ is the spectral emittance, h is the Planck's constant ($6.62 \cdot 10^{-34}$ Js), c is the speed of light ($3 \cdot 10^8$ ms^{-1}), λ is the wavelengtn metres, k is Boltzmann's constant ($1.38 \cdot 10^{-23}$ JK^{-1}), T is the temperature in K and ε_λ is the spectral emissivity.

This formula also implies that with the rise in temperature of the ground objects, there is an increase in the intensity of the emitted radiations, with the peak shifting towards shorter wavelengths. Inverting Planck's equation we get

$$\therefore \; T = \frac{C_2}{\lambda \cdot \ln\left(\left[\varepsilon_\lambda \cdot C_1 \cdot \lambda^{-5} / W_\lambda \right] + 1 \right)} \qquad (4)$$

where $C_1 = 2\pi \cdot h \cdot c = 3.742 \cdot 10^{-16}$ Wm^{-2} and $C_2 = \frac{h \cdot c}{k} = 0.0144$ mK .

For converting digital values from remote sensing data to spectral radiance and to radiant temperatures the reader is referred to the paper by Markham and Barker (1986) as well as Prakash and Gupta (1998).

3 ISSUES

Due to the fundamental difference between remote sensing in the thermal infrared region and the other regions of the EM spectrum, there are some issues peculiar and pertinent for thermal remote sensing. Some of these relate to the mode of acquisition, calibration, radiometric and geometric correction, and are discussed in the following sections:

3.1 Data acquisition: Modes and platforms

There are three different aspects which must be considered while talking about the mode of thermal data acquisition. These are

3.1.1 Active versus passive mode: Most of the thermal sensors acquire data passively, i.e. they measure the radiations emitted naturally by the target/ground. Data can also be acquired in the TIR actively deploying laser beams (LIDAR). However, these techniques are not well researched and are only in the infancy.

3.1.2 Broad band versus multispectral mode: For the broad band thermal sensing, in general the 8 to 14 µm atmospheric window is utilised. However, some spaceborne thermal sensors such as Landsat Thematic Mapper Band 6 operate in the wavelength range of 10.4 to 12.6 µm to avoid the ozone absorption peak which is located at 9.6 µm. The multispectral thermal channels, such as those in the ASTER platform, are targeted specially for geological applications.

3.1.3 Daytime versus night-time acquisition: Thermal data can be acquired during the day and during the night. For some applications it is useful to have data from both the times. However, for many applications night-time or more specifically pre-dawn images are preferred as during this time the effect of differential solar heating is the minimal.

The platforms for such data acquisitions range from satellites, aircrafts to ground based scanners.

3.2 Spatial resolution and geometric correction

Most thermal sensors have onboard recording and calibration systems. Two black bodies (BB) commonly known as BB1 and BB2 are setup which control the radiometric calibration of the acquired data. As the sensors measure emitted radiations, there is also a heating effect and constant cooling of the sensors is required. This poses a physical limit to the measuring capability of the sensors and therefore the spatial resolution of the acquired data. The coarse spatial resolution, specially of satellite borne broad band thermal data poses some additional problems in geometrically registering it to other data, specially when the latter have much higher spatial resolution. Identification of corresponding reliable control points on data sets with such wide differences in spatial resolution is not only difficult but when tried may result in unacceptable transformation results. Alternate approaches of co-registration must be thought of. This may be done by first registering the thermal image to another image with intermediate spatial resolution and in the next step to the target high resolution image. For details on this two step transformation the readers are referred to the paper by Prakash *et al.* 1999.

4 APPLICATIONS

Thermal property of a material is representative of upper several centimetres of the surface. As in thermal remote sensing we measure the emitted radiations, it proves to be complementary to other remote sensing data and even unique in helping to identify surface materials and features such as rock types, soil moisture, geothermal anomalies etc. The ability to record variations in infrared radiation has advantage in extending our observation of many types of phenomena in which minor temperature variations may be significant in understanding our environment. Thermal remote sensing reserves immense potential for various applications. The following is a list of some of the areas in which thermal data is put to use

- Identification of geological units and structures
- Soil moisture studies
- Hydrology
- Coastal zones
- Volcanology
- Forest fires
- Coal fires
- Seismology
- Environmental modelling
- Meteorology
- Medical sciences
- Vetenary sciences
- Intelligence / military applications
- Heat loss from buildings
- Others

Details on how thermal data is processed and used in these various applications is beyond the scope of this article. Numerous references can be found in literature for the use of thermal data for most of these applications. A modest collection of these reference sources is also available at http://www.itc.nl/~prakash/research/thermal_ref.html

5 CONCLUSIONS

From the issues addressed in section 3 of this article, some limitations of thermal remote sensing are clear. On the other hand, from the variety of possible applications highlighted in section 4, the advantages and potentials of thermal remote sensing are also obvious. One more fact that is now clear is that new satellite and airborne platforms with new and improved thermal sensors also promise to bring more interest and challenge in this relatively less explored field. Therefore, now there is a definite need to promote the understanding and the use of thermal data by the scientific and application community. These developments should encompass among other things

- fundamental research in the principles of thermal remote sensing
- laboratory measurements of spectral response of natural materials in the thermal infrared region
- development of more sophisticated sensor technology
- finally to application oriented research where the already explored application fields can be refined and new application areas can be tapped.

One of the most promising way to ensure that such a goal is achieved in by introducing the topic of thermal remote sensing in greater depth in the remote sensing educational programmes. The 'spin off ' effect of such a venture would be that more and more researchers with fresh ideas would explore the thermal data and its possibilities.

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