TIR (ASTER) Geothermal Anomalies

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Keywords

Thermal infrared, geothermal anomalies, geothermal exploration

ABSTRACT

The focus of this research is the detection of shallow thermal anomalies for geothermal exploration and field management. The objective of this paper is to outline the steps involved in applying thermal infrared imagery (TIR) for this task. This process is part of an ongoing project at the Energy & Geoscience Institute (EGI), where we are developing a methodology to use daytime and nighttime thermal infrared imagery produced by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to map shallow thermal anomalies. Kinetic temperature images derived from ASTER TIR data can be used to detect potential anomalies, however, the interpretation process is complex. A key problem is thermal inertia. As different types of ground cover have a wide range of thermal inertia, true geothermal related thermal anomalies are difficult to identify.

Introduction

In the past, obvious surface geothermal manifestations could be used in the search for potentially economic geothermal systems. Modern exploration must focus on blind systems or better characterization of known systems for expansion of production. Remote sensing has evolved as one of the most efficient and cost effective exploration technologies for these types of exploration. Remote sensing is particularly effective for large area screening or characterizing.

Using remotely sensed thermal infrared (TIR) data to measure and identify surface *temperature* anomalies is not a new concept; however, there is little information that appears in the literature regarding this methodology for geothermal exploration in the USA. Airborne data collected by the NASA Thermal Infrared Multispectral Scanner (TIMS), the NASA ATLAS scanner, and satellite data collected by Landsat Thematic Mapper (TM), and the NASA Heat Capacity Mapping Mission (HCMM) have all been used in geologic studies. Several authors have evaluated the potential of these data for geologic mapping, mineral exploration, and for determining thermal inertia (Abrams et al., 1984; Kahle et al., 1984; Hook et al., 1998; Price, 1985; Allis et al., 1999). The authors conclusions indicate overall, that both spatial and spectral resolution have been major limiting factors. In the past, data gathered by satellite or aircraft have not had the ideal combination of a fine spatial resolution with enough spectral information in the thermal infrared to be adequate for geologic purposes. With recent advances in sensor technology, both airborne and spaceborne, there is a strong move to re-evaluate the utility of thermal remote sensing for geothermal and geologic applications. New thermal infrared remote sensing instruments with a higher spatial resolution and an increase in the number of thermal multispectral bands are showing greater potential for application to geologic studies, specifically for site characterization and thermal anomaly detection.

One of the newest satellites, launched in 1999, is the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which is part of the Earth Observing System (EOS) program. The ASTER instrument collects information in both the multispectral and TIR range and can be collected for day and night over an area of interest. This yields a wealth of information in both the reflective and the thermal regions of the electromagnetic spectrum. By analyzing data from both regions, we should be able to improve our characterization capabilities significantly. This will be critical for geothermal exploration.

Background

ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry, and the Earth Remote Sensing Data Analysis Center. ASTER is an on-demand instrument, which means that data will only be acquired over a location if a request has been submitted to observe that area. Any data that ASTER has already acquired are available to all by ordering from the Earth Observing System Data Gateway (EDG). Higher level data products are only produced on demand (ASTER Handbook).

The ASTER instrument collects data in 14 bands, nine visible and near IR (VNIR) bands and five thermal infrared bands. The spatial resolution for the VNIR bands are 15m covering between 0.5 to 0.9 µm in the electromagnetic spectrum and 30m in the short-wave infrared (SWIR), covering between 1.6 µm – 2.4 µm of the spectral range. The spatial resolution for the thermal or emissive bands is 90m covering between 8.1 µm – 11.6 µm of the spectral range.

There are many products that are developed from data collected by the ASTER instrument and they can be broadly characterized into three classes related to processing as follows:

- Level 1A – consists of image data that has radiometric and geometric coefficients but not calibrated, in other words the raw data.
- Level 1B – consists of image data from Level 1A, that has been radiometrically and geometrically calibrated.
- Level 1AE and Level 1BE are expedited products. They differ from the Level 1 A & B products in the information available at the time of processing, and for the most part, the quality is lower that the Level 1A &B.

All of the data are Level 2 products or On Demand Products, processed for specific purposes. For example brightness temperature at sensor is produced for research that requires brightness temperature for the study area. Another example is surface emissivity to be used in research requiring emissivity values for environmental features in the study area.

Working With Thermal Infrared Imagery

In any research project, and perhaps more so when working with remotely sensed data, one must be familiar with the study area. This is especially true when working with thermal data, due to the many variables and physical properties that will affect the outcome of the analysis. Historically, the main reason for using TIR data was to estimate relative land surface temperature. In many cases, researchers use the values from thermal bands from airborne or satellite data without taking into consideration atmospheric properties, emissivity properties (discussed below), or soil moisture. All of these parameters will affect the accuracy of the analysis. In some cases, emissivity values will be assigned a constant to all pixels in the dataset, which does not take into account the sites heterogeneity. As concluded by Brunsell and Gillies, (2002), it is important to incorporate emissivity values when dealing with TIR data - so important that using any methodology to do so is better than none at all.

Ideally, the values we obtain in thermal remote sensing will correlate closely to the object's true kinetic temperature, but they do not. This is due to emissivity. All materials have unique emissivity values. Before explaining emissivity, the concept of a blackbody must be introduced. In theory a blackbody is a perfect absorber and perfect emitter; all the radiant energy that falls on it is absorbed. Energy is then re-radiated at the maximum possible rate. There are no true blackbodies, with the sun being the closest example. Emissivity then, is the ratio between the radiant flux exiting a real world object or feature and a blackbody at the same temperature. The emissivity of a blackbody is 1 and all other radiating objects have emissivity values between 0 and 1. For example, most vegetation has emissivity values close to 1 and many minerals have emissivity values much less than 1. The reason it is important to know this in thermal remote sensing, is that two objects lying close together on the ground may have the same kinetic temperatures, but different emissivities. If the emissivity values were not known, the two objects could be mistaken to be the same. Emissivity values are influenced by color, surface roughness, moisture content, density, and wavelength.

Familiarity with thermal properties of the terrain is critical in a project using TIR data. All objects that have temperatures above 0 Kelvin contain kinetic heat, which can be measured *in situ* with a thermometer. Kinetic heat is converted to radiant energy and this energy, as it is emitted from an object, is called radiant flux. The concentration of radiant flux is referred to as radiant temperature and this is what the thermal bands on the sensors record in the thermal portion of the electromagnetic spectrum. These values are sometimes called apparent temperatures. By obtaining nighttime and daytime thermal infrared data, we can compute apparent thermal inertia measurements. Thermal inertia is "a measurement of the thermal response of a material to temperature changes" (Jensen, 2000). The thermal images are geometrically and radiometrically registered to one another and then subtracted resulting in a temperature change between the two as shown in the following equation:

$$ATI = \frac{(1 - Albedo)}{\Delta T}$$

Where albedo = reflectance in daytime visible data and ΔT = change in temperature between the day and night thermal imagery.

A high ΔT value is usually associated with materials or features having a low thermal inertia, while a low ΔT value is usually associated with materials or features having a high thermal inertia (Jensen, 2000).

Temperature is a variable property of the terrain, varying with meteorological conditions and land cover material. Emissivity is an inherent property of the terrain with each feature having a unique value for emissivity. Thus, knowing something of the atmospheric conditions, weather, time of day the data was collected, and emissivity values of the area will be critical in accurate data analysis. Thermal anomalies should be conspicuous departures from the average values based on known information. However, there are still limitations, "because (1) VNIR spectral images do not yield unique compositional information and (2) surface coatings on exposed materials can mask their true composition" (Abrams et al., 1984).

The advantage of using ASTER data for research is that there are many On Demand Products that address most of the considerations mentioned above. The ASTER science teams are continuously testing different algorithms to maintain and improve the high quality of the data, and for validation and calibration purposes.

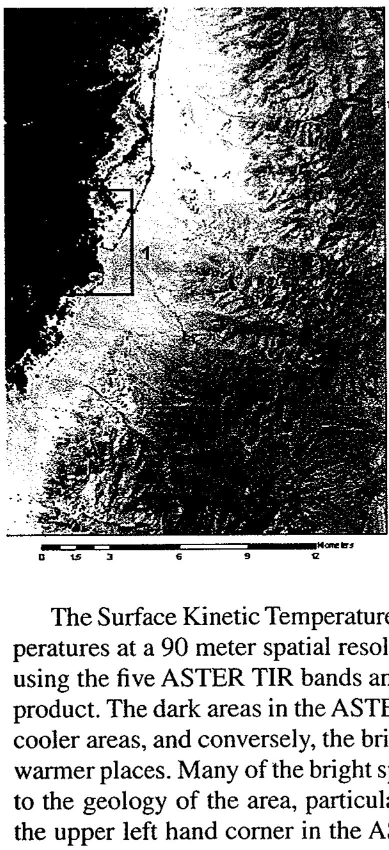
EGI Research

The scientific approach we propose in relating perceived thermal anomalies to actual geothermal activity is predicated on the analysis of remote sensing data in conjunction with *in situ* data (i.e., geologic and vegetation assessments). Remote sensing data form the basis for detecting anomalous surface temperature distributions, for mapping structure from temperature differentials, and serve as an input to mineralogy mapping. These remotely sensed data will be used to provide input to geothermal models that relate thermal anomalies to possible hydrothermal alteration.

A proposal for data acquisition over the study areas for the research at EGI was submitted October 2002 and has been successfully acquired. It is now in Japan being processed through the Ground Data System (GDS).

Preliminary Analysis

To expedite methodology development, imagery was obtained of an area in Central Nevada to facilitate preliminary research (Figure 1). On the left is a Landsat TM image and on the right is a surface kinetic temperature image produced by the ASTER Science Team.



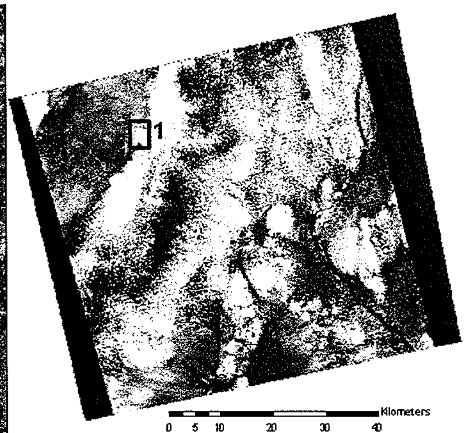


Figure 1. Landsat TM image on the left and ASTER surface kinetic temperature image on the right.

The Surface Kinetic Temperature image contains surface temperatures at a 90 meter spatial resolution. The data were derived using the five ASTER TIR bands and a Land Surface Emissivity product. The dark areas in the ASTER image represent relatively cooler areas, and conversely, the bright areas represent relatively warmer places. Many of the bright spots on the image correspond to the geology of the area, particularly mafic rock out-crops. In the upper left hand corner in the ASTER image as indicated by the box and number 1, there appears to be an anomaly, which in the TM image on the right, corresponds to the edge of the playa. This light area does not correspond to any known geologic feature and therefore, demands further inspection. The highest temperature in this area was calculated to be 75.29 degrees Fahrenheit or 24.05 degrees Celsius. The pixel values in the Surface Kinetic Temperature image are in degrees Kelvin. The ASTER image was acquired at 10:30 pm on October 3, 2002. To determine if this is indeed a thermal anomaly, much more analysis needs to take place. We are in the process of determining what data we need to obtain for calculating thermal inertia. One of the variables in the equation is albedo. Albedo is reflectance measured in the visible part of the spectrum during the daytime. There is some question as to which ASTER on demand product would work best. ASTER Science Team members are currently discussing this issue at the Jet Propulsion Laboratory. We hope to have an answer soon to continue with our preliminary analysis.

Conclusions

TIR data can be a valuable asset in geothermal exploration and field management. It is useful for structure and mineralogy mapping, and thermal anomaly detection and mapping. However, TIR data may be the most complicated type of remote sensing data to unravel. Without proper processing interpretation can be unreliable, particularly for structural mapping and thermal anomaly detection and mapping. EGI personnel are currently working closely with NASA TIR experts to develop a proper methodology to address the complex issues involved in TIR processing. As the project moves forward, images will be posted at the following site: http://www5.egi.utah.edu/

Acknowlegment

This Work is supported by the U.S. Department of Energy under DOE Idaho, Operations Office Contract DE-AC07-001ID13891.

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