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Detection of geothermal anomalies using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) thermal infrared images at Bradys Hot Springs, Nevada, USA

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Abstract

Surface temperature anomalies associated with geothermal activity at Bradys Hot Springs, Churchill County, Nevada were mapped using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) thermal infrared (TIR) image data. In order to highlight subsurface contributions of geothermal heat, the ASTER images were processed to minimize temperature variations caused by the diurnal heating effects of the sun. Surface temperature variations caused by changes in albedo were corrected with visible and near-infrared ASTER bands, and a 10-meter-smoothed Digital Elevation Model (DEM) was used to correct for topographic slope effects. Field measurements of ground surface temperatures made over 24-hour periods were used to design a thermal inertia correction incorporating day and night thermal infrared images.

In the resulting processed image, background temperature variations were reduced 30–50% without reducing the intensity of geothermal anomalies, thus making it easier to distinguish geothermal activity from 'false' anomalies caused by non-thermal springs, topographic effects, and variable rock, soil, and vegetation compositions.

Keywords: Thermal infrared; Geothermal; ASTER; Bradys; Nevada; Great Basin

1. Introduction

This paper investigates the ability of ASTER images to detect surface temperature anomalies associated with geothermal activity (hot springs and fumaroles) in the Great Basin of the western United States. The Great Basin is a region of internal drainage characterized by active faulting, crustal extension (Stewart, 1983), and high crustal heat flow (Blackwell, 1983), and contains a number of high-temperature (>150 °C) geothermal systems with an installed electric power plant capacity of nearly 600 MW. The Great Basin (Fig. 1) is well suited for remote sensing exploration for geothermal resources because geothermal systems occur over a large area, there is relatively sparse vegetative cover in an arid environment, and because deep water tables sometimes impede the formation of hot springs that otherwise would signal the presence of subsurface geothermal activity.

Remotely sensed thermal infrared (TIR) images have been used for years to detect geothermal activity (Allis et al., 1999; Lee, 1978), but the success of those efforts in some cases has been limited by the difficulty in modeling the diurnal heating effects caused by the sun. An example of where this is a challenge is the main sinter terrace at Steamboat Springs, NV, where a conventional pre-dawn thermal image does not detect a thermal anomaly (Fig. 2a) in spite of numerous fumaroles being present. The terrace has a relatively high albedo and reflects much of the sun's energy during the day. It has a low thermal inertia because of its high porosity and a currently low water table, and consequently cools off quickly at night. A recent study by Coolbaugh et al. (2000) demonstrated that it was possible to compensate for the effects of albedo and thermal inertia to reveal the underlying thermal anomaly (Fig. 2b) at the terrace. It should be noted in passing that although hot springs and geysers were present at this terrace as recently as 1987 (Koenig, 1989), the water table has since dropped to at least 30 m below the surface (Platt, personal communication, 2002) as a result of water withdrawal from

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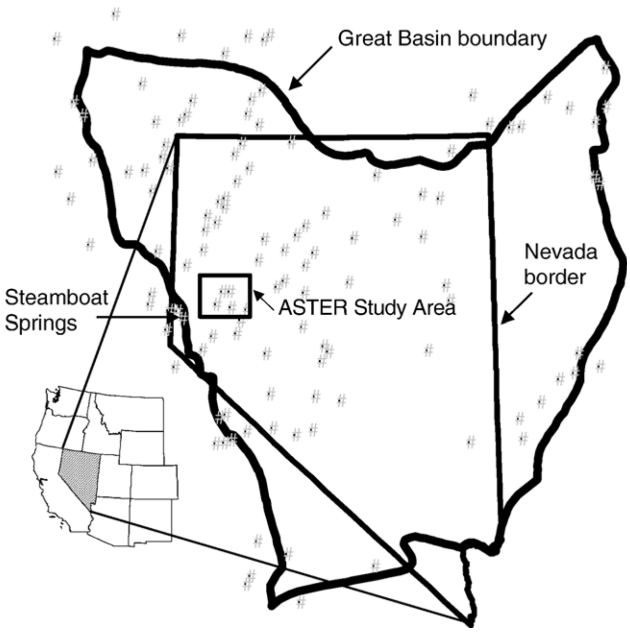

Fig. 1. Location map of ASTER and Steamboat Springs study areas. Grey circles are known geothermal systems with measured or calculated temperatures of 100 °C or greater.

nearby wells. Steam still rises along open fissures to form weak fumaroles, but observations by the authors confirm that the highly porous sinter is essentially dry where observed within 1–2 m of the surface, thus helping to explain its low thermal inertia.

The initial success of the Steamboat study, which used the Thermal Infrared Multispectral Scanner (TIMS) from an airborne platform, encouraged efforts to validate and refine the techniques using satellite-derived images. ASTER images were acquired over the Hot Springs Mountains in west-central Nevada (Figs. 1 and 3). This area contains several geothermal occurrences, one of which, at Bradys Hot Springs, has an extensive surface expression of fumaroles, mud pots, and warm ground (Fig. 4) that follow surface traces of Quaternary faults for a distance of 4 km.

The Hot Springs Mountains and the Truckee Range to the west (Figs. 3 and 4) are faulted horst blocks consisting of Tertiary basaltic and andesitic volcanic rocks interbedded with lacustrine sediments including diatomite. Intervening valley grabens (some of which are labeled as "sinks" in Fig. 3) contain colluvium, alluvium, sand dunes, and playa evaporite deposits. Vegetation in hills and mountains consists of relatively sparse sage and salt brush: grass is locally present in wet areas or marshes.

2. Material studied and software used

Day and night ASTER scenes were acquired on the same date, Aug. 31, 2001, with the assistance of the Jet Propulsion Laboratory (JPL) in Pasadena, CA. Weather was dry and hot, with maximum temperatures near 35 °C and little wind; a light haze was present due to distant forest fires in California and visibility was approximately 60 km. Skies were clear prior to and during the morning ASTER flyover, but isolated cumulus clouds locally developed in the late afternoon. No rain fell, but the clouds reduced the amount of late afternoon sun received in some areas. After sunset, cloud cover increased from 20% to nearly 100%, but then largely dissipated 1 h before the nighttime ASTER flyover. Scattered clouds visible on the nighttime image were avoided when the thermal anomaly algorithms were designed.

Preprocessed digital versions of the ASTER images were downloaded from the EROS data center at http://edcdaac.usgs.gov/asterondemand/index.html: those versions include the ASTER higher-level data products AST07 (surface reflectance)

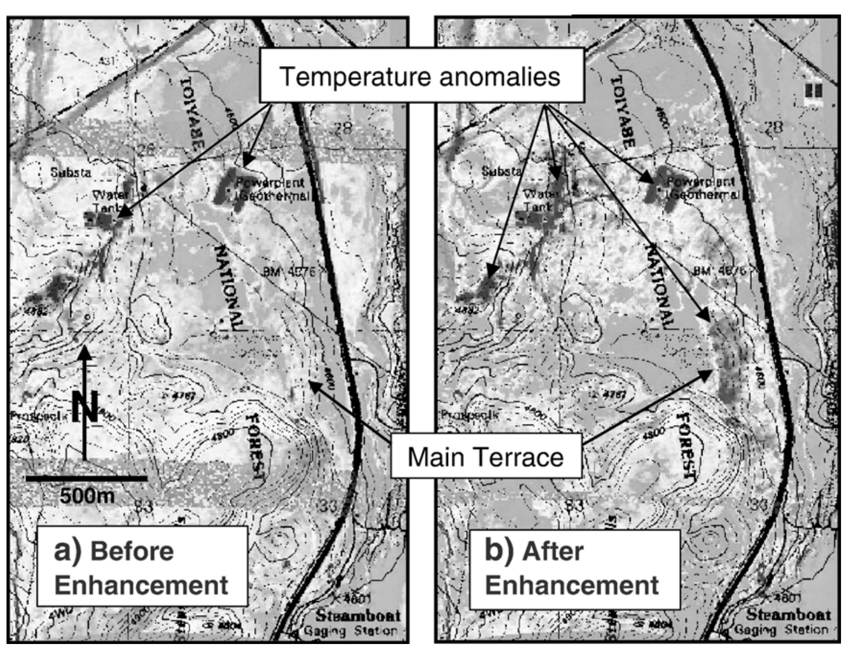

Fig. 2. Before and after enhancements of Thermal Infrared Multispectral Scanner (TIMS) images at the Steamboat Springs main sinter terrace. Darker shades denote temperature anomalies. A pre-dawn thermal image (a) does not detect an anomaly at the Main Terrace. After processing to compensate for the cooling effects of high albedo and low thermal inertia, a temperature anomaly related to geothermal activity is revealed (b).