GEOLOGIC REMOTE SENSING IN THE THERMAL INFRARED

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ABSTRACT

Remote sensing of emitted radiance from the Earth's surface in the thermal infrared region (8 to 13 μm) is useful for geologic studies including lithology and soil and mineral mapping. Since 1982, new airborne, field portable and spaceborne instruments have been demonstrating the advantages of multispectral measurements in this region for geologic applications. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), presently being built in Japan, is the newest of the spaceborne multispectral instruments. ASTER, which has fourteen channels in the visible out through the thermal infrared, will be flown aboard NASA's EOS AM1 platform in 1998. Other multispectral instruments, including PRISM, IRSUTE and Sacagawea, are projected to be built and flown after ASTER. The advent of these sensors is expected to result in a demand for more high spatial-resolution multispectral thermal infrared data.

INTRODUCTION

The feasibility of using multispectral thermal infrared remote sensing for geologic applications has been recognized by a number of users, but advancement has been limited by lack of sensors. The use of the visible and near infrared (VNIR) and shortwave infrared (SWIR) spectral data made a tremendous leap forward with the advent of the Landsat satellite sensors (MSS, TM). We anticipate a similar phenomenon when orbital multispectral thermal infrared data becomes generally available with the launch of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) in 1998. The ASTER instrument will be the first spaceborne multispectral thermal infrared instrument with spatial and spectral resolution adequate for geologic applications. From thermal data one can derive both surface temperature and surface spectral emissivity. The primary application of the emissivity is for surface lithologic mapping. The temperature data can be used both for studies of thermal inertia of surface materials, and for studies of thermal processes related to volcanism and hydrology.

THEORETICAL BACKGROUND

At terrestrial temperatures, the thermal infrared spectral radiance emitted by the surface is at a maximum around 10 to 11 μm, dropping off sharply to the shorter and longer wavelengths. The best atmospheric window lies between about 8 and 13 μm with another window between 3 and 5 μm. Interpretation of data from the 3 to 5 μm region is complicated by overlap with reflected solar radiation which, although dropping rapidly in intensity with increasing wavelength, makes a large contribution during the day. Thus, the 8 to 13 μm region is the best thermal infrared spectral region to use and has received most attention to date. This is also a spectral region containing diagnostic spectral information for many minerals, including the silicates which make up the great majority of continental surface rocks.

Spectral features of minerals in the thermal infrared region are the result of vibrational molecular motions. The location, strength and form of these features vary systematically with composition and crystal structure. The most intense band in the spectra of all silicates (the reststrahlen effect) occurs between 8 and 12 μm. Typically, this spectral feature shifts to shorter wavelengths as the bond strength within the lattice increases (Hunt, 1980; Lyon, 1965). The carbonates, sulfates, phosphates, and hydroxides are other important mineral groups that have spectral features in the thermal infrared (Hunt and Salisbury, 1974, 1975, 1976).

The range of minerals found in soils is usually quite limited, particularly with older, more developed soils, in which iron oxides, quartz and clays almost always dominate, except in arid climates where carbonates may be important. The relative amounts of these minerals should vary systematically, depending on climate and the composition of the parent rock. Using remote sensing, these minerals can all be detected and identified, based on their spectral properties. Iron oxides produce absorption features in the VNIR, clays and carbonates in the SWIR, while quartz has characteristic features only in the thermal infrared (TIR). Thus, remote soil mapping, like geologic mapping, will be enhanced by combining VNIR, SWIR and TIR wavelength regions.

In addition to the spectral emissivity, accurate values of ground surface temperature can also be determined by multispectral thermal IR measurements. If these surface kinetic temperature and emissivity measurements are made on a diurnal basis, then one can also calculate thermal inertia of the surface materials, using appropriate models (Kahle, 1977; Kieffer et al., 1977). Thermal inertia provides a measure of the effective particle size of dry material and can be a useful tool for discrimination and mapping of bedrock versus surficial deposits. Day-night temperature variation also provides an indication of moisture at or near the surface, as the heat of evaporation moderates diurnal temperature variation.

AIRBORNE AND FIELD PORTABLE SENSORS

Since 1982, NASA's airborne Thermal Infrared Multispectral Scanner (TIMS) has allowed demonstration of the utility of this wavelength region for geologic applications (Kahle and Goetz, 1983). TIMS has six spectral channels between 8.0 and 11.7 μm, with a NEΔT of ≤0.2K in each channel, and an IFOV of 2.5 milliradians which provides ground resolution from 5 to 50 m, depending upon aircraft altitude. Like the initial airborne sensors that provided the stimulus for space platforms in the VNIR, this instrument has demonstrated the utility of this wavelength region for compositional mapping, has proven that we can observe spectral features on natural surfaces, and has helped to define the functional requirements for thermal infrared remote sensing instruments. Other airborne instruments are now available including the Multispectral Infrared and Visible Imaging Spectrometer (MIVIS), the Airborne Hyperspectral Scanner (AHS) built by Daedalus, the Geoscan Scanner from Australia, the ATLAS Sensor developed and flown by Stennis Space Center, and the MODIS Airborne Simulator (MAS), flown at NASA's Ames Research Center. In addition, portable field spectrometers have become available including the μFTIR from Designs and Prototypes (Hook and Kahle, 1995), the MIDAC instrument from MIDAC that has been used both in aircraft and on the ground to measure downwelling and upwelling radiance and THIRSPEC, developed in Canada by Rivard, et al. to provide geologic ground truth in support of airborne and satellite data. These new instruments further demonstrate the interest in the thermal region for geologic applications.

SPACEBORNE INSTRUMENTS

Over the last several years, instruments have been flown in orbit to image the Earth's surface in a few thermal infrared bands at a spectral resolution of about a kilometer or more. These include such instruments as AVHRR and ATSR. While these instruments have proved extremely useful for measurement of sea surface temperature, their utility over land is somewhat reduced because of the high spatial variability of land surfaces and the nonuniform spectral emissivity of the land surface materials. These factors combine to make an accurate determination of land temperatures difficult. Landsat, while having a better spatial resolution in the thermal infrared — 120 m — has had only a single channel in this wavelength region so no multispectral data could be obtained. However, in the next few years we can anticipate new instruments which will have several to many bands in this region with much higher spatial resolution. These new instruments will allow much more accurate determination of surface spectral emissivity and surface temperature. One of the first of this new generation of thermal infrared imaging instruments will be ASTER. Other projected instruments include PRISM from ESA (Rast and Kealy, 1993), IRSUTE from CNES (Durpaire et al., 1995), and Sacagawea from NASA, but they will probably be a couple of years or more later than ASTER.

ASTER (Yamaguchi, et al., 1994; Kahle et al., 1991; Fujisada, 1995) is a facility instrument selected for launch in 1998 on the first NASA Earth Observing System spacecraft, EOS-AM1 (Asrar and Dokken, 1993). The ASTER instrument is being sponsored and built in Japan, with funding provided by the Japanese Ministry of International Trade and Industry (MITI). The Japan Resources Observation Systems Organization (JAROS) is responsible for the design and development of ASTER which is subcontracted by JAROS to NEC, MELCO, Fujitsu and Hitachi.

The objectives for the ASTER instrument are to obtain high spatial resolution multispectral targeted data in the visible and infrared wavelength regions. An international team of scientists are developing the algorithms and software that will be used to process the data from the instrument into standard and special data products. The standard data products will be produced at the Earth Resources Observation System (EROS) Data Center (EDC) Land Processes Distributed Active Archive Center (LPDAAC) at Sioux Falls, South Dakota. Special data products will be produced by the Science Team members at their home institutions.

The ASTER standard data products that will be ready at launch will include radiance at the sensor, brightness temperature at the sensor, atmospherically-corrected surface-leaving radiance, surface emissivity, surface kinetic temperatures, decorrelation stretch images and local Digital Elevation Models (DEMs). In addition, other standard data products may be developed postlaunch, and several special data products will be produced by the ASTER investigators at their home institutions. These data products can be used by the general science community in studies of geology, surface radiation balance, evaporation and evapotranspiration, vegetation, soils, the hydrogeologic cycle, surface-atmosphere fluxes, surface change detection, glacial studies, volcanic processes, sea ice and clouds.

ASTER is comprised of three radiometers: (1) a three-channel visible-near infrared two-telescope radiometer (VNIR) that is capable of providing stereo data for the production of digital elevation models, (2) a six-channel shortwave infrared radiometer (SWIR), and (3) a five-channel thermal infrared radiometer (TIR). All three radiometers can be operated independently and all three are individually pointable. The instrument features high spatial and radiometric resolution. The nadir-viewing swath width is 60 km. With its pointing capability, ASTER is capable of viewing any point on Earth every 16 days. Because of its polar orbit, it can view any point above 45° every 7-9 days and any point above 69° every 3-4 days. It takes 48 days to provide full surface coverage.

The ASTER characteristics are given in Table 1.

Table 1. ASTER

Radiometer	Spectral range	Data rate	Radiometric resolution	Spatial resolution
VNIR	Nadir bands 0.52-0.60 μ 0.63-0.69 μ 0.76-0.86 μ Stereoscopic band 0.76-0.86 μ	62 Mbps	<0.5%	15 m
SWIR	6 bands 1.6-1.7 μ 2.145-2.185 μ 2.185-2.225 μ 2.235-2.285 μ 2.295-2.365 μ 2.360-2.430 μ	23 Mbps	<0.5%-1.3%	30 m
TIR	5 bands 8.125-8.475 μ 8.475-8.825 μ 8.925-9.275 μ 10.25-10.95 μ 10.95-11.65 μ	4.1 Mbps	<3K	90 m

Instrument and spacecraft resources are allocated to support an 8% average duty cycle. ASTER data will be acquired and processed according to specific user requirements identifying acquisition time, gain, wavelength region, and data product. For daytime observations, the user may request that any or all of the three subsystems be operated. For nighttime observations, typically only the TIR subsystem will be employed, but it is possible to request both TIR and SWIR at night for hot volcanic targets. Current plans are that all EOS investigators, and other scientists approved by NASA or MITI will be allowed to submit requests for data acquisition over their targets. Additionally, the ASTER Science Team, working with the IDS Teams, will define targets such as active volcanoes, which should be monitored routinely, and a one-time global land surface map will be created over the six-year life of the mission. Data, once acquired, will be available to all investigators.

SUMMARY

The next decade should prove to be an exciting one for geologists using thermal infrared remote sensing. Just as Landsat developed a large user community in the 1970s when multispectral VNIR data became available over users' areas of interest, we anticipate that the advent of the sensors discussed here will develop a demand for high-spatial-resolution multispectral, thermal infrared data. It is important that the technology be developed to allow continued improvement in these types of instruments.

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