VOLCANIC THERMAL FEATURES OBSERVED BY AVIRIS

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1. INTRODUCTION

In July 1991, AVIRIS was flown over Mount Etna and Stromboli, Italy. Lava-filled vents were then present within summit craters of both volcanoes. Since surfaces at magmatic temperatures radiate strongly over the wavelength ranges of the AVIRIS C- and D-spectrometers, it was hoped that the data collected would reveal clear thermal signatures, even of sub-pixel sized features, as have been observed in the 1.65 and 2.22 μm bands of Landsat Thematic Mapper images (*Rothery et al.* 1988). This would provide an opportunity to explore the potential of imaging spectrometers for deriving temperature distributions of hot volcanic surfaces. Such research has implications for volcano monitoring in the EOS era, and also for any future AVIRIS deployments above active lava flows, lakes and domes, where understanding of their behaviour may be advanced by detailed thermal observations (*Pieri et al.* 1990, *Oppenheimer* 1991).

2. DATA INTERPRETATION

AVIRIS recorded useful data of Stromboli on July 8, 1991 (910708B run 8 segment 1) and Mount Etna on July 19, 1991 (910719B run 7 segment 3). Despite a seven-fold loss of throughput in the D-spectrometer resulting from faulty fiber-optics (R. Green, pers. commun. 1992), there are pronounced thermal responses in this part of the spectrum (1.8-2.45 μm), as well as in the C-spectrometer output (1.2-1.8 μm), to summit features at both volcanoes. No sensor saturation occurred, reflecting the wide dynamic range of AVIRIS (up to about 20 mW cm^{-2} sr^{-1} μm^{-1} for the healthy D-spectrometer).

The radiometrically calibrated data were processed in the following manner. It is assumed that the measured spectral radiance, R_λ, in each AVIRIS channel is the sum of partially transmitted reflected sunlight and skylight, any path radiance, and partially transmitted thermal radiation from one or more components of the surface:

$$R_\lambda = \tau_\lambda \rho_\lambda R_{\lambda,D} + R_{\lambda,U} + \tau_\lambda \sum_i \varepsilon_{\lambda,i} f_i \, L(\lambda,T_i) \qquad (1),$$

where τ_λ is the atmospheric transmittance at wavelength λ, ρ_λ the spectral reflectivity of the surface, $R_{\lambda,D}$ the downwelling atmospheric radiance, $R_{\lambda,U}$ the upwelling path radiance, $\varepsilon_{\lambda,i}$ the spectral emissivity of the *i*th surface thermal component, f_i its pixel-filling fraction, and $L(\lambda,T_i)$ the spectral radiance from the *i*th thermal component with a surface absolute temperature T_i, which is given by the Planck distribution law as follows:

$$L(\lambda,T_i) = \frac{c_1 \lambda^{-5}}{\exp(c_2/\lambda T_i) - 1]} \qquad (2),$$

where c_1 and c_2 have the values 1.19 x 10^{-16} W m^2 and 1.44 x 10^{-2} m K, respectively.

For a "hot" pixel, the radiated component of the spectrum was isolated by first subtracting, band-by-band, the spectrum of a neighbouring "cool" pixel. This was deemed to be optimized when the residual spectrum showed the least net signal between 0.4 and 1.2 µm. Next, the "difference" spectrum was divided, band-by-band, by a file containing atmospheric transmission coefficients (obtained using LOWTRAN 7) convolved with the AVIRIS spectral response file. Figure 1 shows a spectrum thus corrected for a single pixel over Stromboli; channels for which the modelled atmospheric transmittance was below 0.5 were excluded. The solid curve shows the best Planck curve fit, found using the Simplex algorithm (*Caceci and Cacheris* 1984), for a single temperature hot spot surrounded by ground too cool to radiate significantly in this region of the infrared. The solution represents a pixel containing approximately 12 m^2 (f=3.72% of a nominal 320 m^2 IFOV) of ground at 598 °C (ε=0.95). This would be consistent with a region of recently erupted spatter, or crusted lava inside a small intracrater bocca, both characteristic of Stromboli's activity at the time (*Smithsonian Institution* 1991).

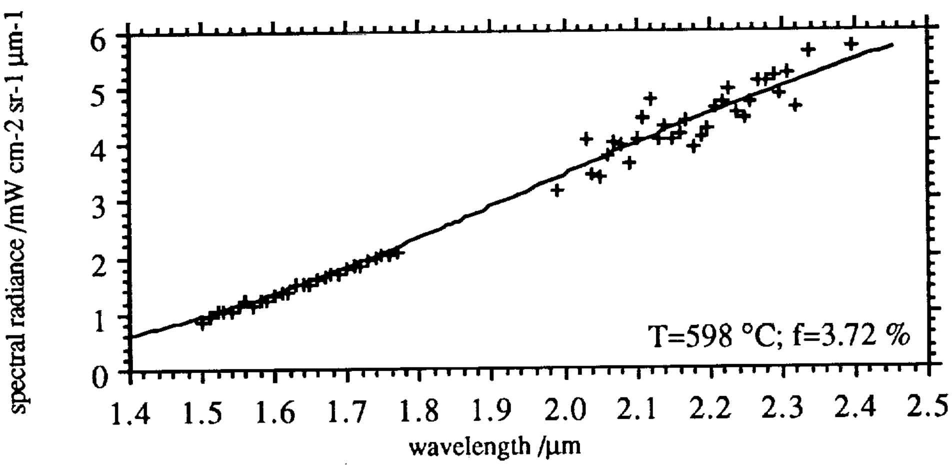

Figure 1. Corrected AVIRIS spectrum and Planck curve fit for a pixel over Stromboli.

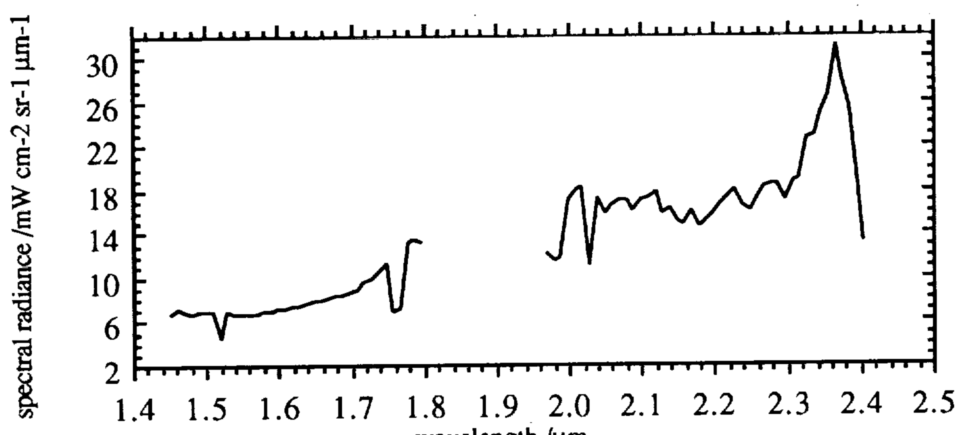

Figure 2. Corrected AVIRIS spectrum for pixel of Northeast Crater, Mount Etna.

Not all the spectra examined have been resolved so convincingly into the sum of Planck radiation curves. Figure 2 shows the most intense thermal anomaly over the Northeast Crater of Mount Etna. This spectrum was derived following the procedure outlined above. Again, the D-spectrometer range is very noisy. Furthermore, the shape of the 1.2-1.8 µm spectrum is not readily interpretable in terms of superposition of different thermal components. In addition to its broadly concave upwards form, there are marked drops in the spectrum at about 1.52 and 1.76 μm. These could represent either false positive-noise-spike corrections, uncorrected dropouts, or genuine absorption features. At the time the image was recorded, the only hot spot within the Northeast Crater was a funnel-shaped pit on its floor. This vent emitted high temperature gases, glowed, and probably contained magma close to the surface (*Smithsonian Institution* 1991). We note that HCl is infrared-active around 1.76 μm but have yet to calculate the concentrations necessary to attenuate emitted radiation to the extent suggested by the AVIRIS data. We plan also to examine the raw AVIRIS data which could exclude the possibility that a noise-spike correction was applied erroneously.

4. DISCUSSION

AVIRIS takes 87 μs to record a spectrum in each detector array. This is about 6 orders of magnitude faster than conventional field spectroradiometers. However, even this brief time is equivalent to approximately one cross-track pixel displacement on the ground. This is corrected for by a linear interpolation of the recorded DN in each detector element between adjacent cross-track samples (*Green et al.* 1991). This will tend to blur thermal anomalies in the cross-track direction and, more worryingly, distort the shape of the spectrum according to the size and position of the thermal feature relative to the instrumental instantaneous field of view. Some of the difficulty experienced in fitting Planck radiation curves to the recorded spectra probably reflects this latter point. Unfortunately, going back to the raw image which has not been resampled presents the original problem that each detector element within a given spectrometer has sampled a different piece of ground. However, corresponding detector elements in each spectrometer are nominally spatially coregistered; perhaps by selecting a few neighbouring data points and plotting them along with those at the same position in adjacent detector arrays, one might derive more reliable thermal results. This problem with interband spatial registration should be less significant for large features with uniform surface temperatures. It would be solved altogether by enabling AVIRIS to record all bands simultaneously; such a proposal is under review (R. Green, pers. commun. 1992).

AVIRIS may be in Hawaii in November 1992, which would, in all likelihood, offer a tremendous opportunity to record data above areally extensive lava flow fields and lava ponds. By deriving radiative properties of such features from the AVIRIS data, one might hope to refine models for, and thereby our understanding of, their eruption.

5. ACKNOWLEDGMENTS

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