What is the Emissivity of Active Basaltic Lava Flows?

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The emissivity of molten lava surfaces has been a topic of study for some time because it directly affects the cooling efficiency of the flow, thermo-rheological models of flow evolution, as well as the accurate interpretation of the bulk composition. Despite past studies, it remains unclear whether the emissivity of molten lava truly is different than that of the cooled surface. Measuring of multiple temperatures, as the lava cools. We therefore see determination of correct surface emissivity and its change with time to be of great importance to anyone working with thermal infrared (TIR) data or modeling of lava flows. A series of high-resolution melting experiments on basalts has been conducted using a novel micro-furnace and TIR spectrometer, producing high-resolution accurate emissivity measurements at known temperatures transitioning from and natural lava surfaces acquired from a newly-developed field-based multispectral camera system, which is capable of generating lower-resolution emissivity spectra. We present the results of the new camera system using both hot solid (obsidian and basalt) and molten (Halemaumau crater lava lake) targets. These results have provided validation of the efficacy of the camera system in a field environment for future deployments as well as a means of constraining TIR data from satellite observations.

Laboratory-Derived Emissivity

A series of laboratory thermal emission spectra were collected in the Image Visualization and Infrared Spectroscopy (IVIS) Laboratory at the University of Pittsburgh. The first set of experiments involved measuring the emissivity of basalt with change in physical state (molten to solid). A custom-built micro-furnace integrated with a Nicolet Nexus 670 FTIR spectrometer with a cooled XT-KBr detector was used to acquire TIR emitted energy from Hawaiian basalt samples at various stages in the melting and cooling process (Figure 1). Approximately 2 grams of basalt sample was crushed into mm-sized pieces, placed into a platinum crucible, and heated to ~200C above the liquidus (~1400C) to ensure a complete melt. In order to acquire emissivity spectra, the micro-furnace chamber is opened via a small sliding door at the top. Thermal emission from the sample is reflected into the spectrometer by way of a collimating mirror, which is situated directly above the sample port of the furnace. Spectra were acquired of the basalt in 100C increments from 1400C to 500C, with the sample held for ~5 minutes at each set point temperature. Significant differences can be seen in the position and depth of emissvity features in the basalt spectra (Figure 2), indicating that thermal emission spectral character changes between molten and solid states.



Figure 1: A) The IVIS Laboratory spectrometer setup, with a Nicolet Nexus 670 FTIR spectrometer and Plexiglas glove box. The setup is continuously purged of CO2 and H2O. The glove box is open to the external port of the spectrometer via a hole, which allows for the sample's emitted signal to pass into the spectrometer during acquisition. (B) The micro-furnace is 21.6 cm in height and 28 cm in diameter at the base, and has an integrated water cooling system. The sliding portion of the top cover moves outward to expose the sample for analysis. (C) The crucible with sample is situated in the central portion of the furnace, and is surrounded by 3 heating elements. The sample is exposed to the spectrometer by sliding the insulated baffle out. (D) Emissivity spectra of a Hawaiian basalt sample at various tempertures. Spectral character is markedly different between solid (< 1200C) and molten (>1200C) states. Specifically, the emissivity minimum value and emissivity minimum position change with increasing temperature, which reflect the change in molecular structure of the sample as it transitions from a molten to a solid state (or vice versa).

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Introduction

The FLIR camera is a hand-held infrared camera capable of acquiring precise (0.08 °C at 30 °C) and accurate (± 2 °C) TIR radiance data at a high spatial resolution. The camera's microbolometer detector collects broadband energy emitted in the 7.5 to 13 µm region. Because of TIR in studies of silicates, FLIR cameras have become increasingly utilized for the study of active and inactive volcanoes and their deposits [1, 2, 4]. The fore optics of a FLIR camera have been modified for use as a multi-spectral TIR field imaging system. The broadband (7.3 to 13 µm) wavelength range has been divided into five individual wavelengths using external diffraction filters [3], making the camera capable of collecting both temperature and emissivity data. The wavelength centers of these filters are 8.3, 8.6, 9.0, 10.6 and 11.3 µm. These wavelengths were chosen because they fall within the wavelength range of major aluminosilicate emissivity spectral features. We have begun calibration of the FLIR/filter system by imaging a sample of basalt using the system. These samples were heated to approximately 90C, in order to provide a hot target. The five images (one for each filter) were used to generate 5-point emissivity spectra of the samples (Figure 2).





Figure 3: (A) Original prototype version of the FLIR/filter system. The filters were mounted on a rail which moved back and forth, placing each filter in front of the FLIR optics as images were acquired. (B) FLIR-derived emissivity image of obsidian (at 8.6 microns), and the corresponding 5-point emissivity spectrum of the obsidian sample, derived emissivity image of a Hawaiian basalt sample (at 8.6 microns), and the corresponding 5-point emissivity spectrum of the basalt sample. Both of these spectra are consistent with lab-derived spectra of the samples, indicating that the filter system is capable of collecting accurate spectra.

Field-testing of the multi-spectral FLIR on molten lavas was first performed at Halemaumau lava lake (Hawaii) in August 2014. Due to a lack of surface basalt flows at the time, the lava lake was an ideal target, as it has dynamic variability and has a mixture of lava crust, molten lava, and SO2 gas. All of these components were detected using the camera system, and the emissivity changed with wavelength, as expected. Most importantly, there is a clear drop in the emissivity of molten basalt (versus solid crust), a behavior also seen in the laboratory basalt samples (Figure 3).





Although further calibration and testing is needed, the FLIR/fliter system has initially shown great promise for deriving spectra of basalts in the field, both in molten and solid states. The system has recently been converted into a filter wheel (left) which moves the filters more efficiently, and allows for more accurate image acquisition. Future work includes utilizing the system to acquire emissivity spectra of active Hawaiian basalt flows at various physical states. A more compact version of this system is currently being developed, and filters have been chosen for the system to correspond with HyspIRI, a new hyperspectral infrared imager operating in low Earth orbit.

References: Carter, A. and Ramsey, M.S. (2009) Rem. Sens. Environ., 113, 2412-2151; Patrick, M. et al. (2007) Bull. Volc., 69, 769-784 DOI: 10.1007/s00445-006-0107-0; Ramsey, M.S. (2009) Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abst. V24B-01; Ramsey, M.S. and Harris, A., (2013) J. Volcanol. Geotherm. Res., doi:10.1016.



Calibration of the Thermal Camera/Filter System

Deriving Basalt Emissivity In The Field



Conclusions and Future Work



Figure 3: (A) FLIR image of Halemaumau crater lava lake at 8.3 microns. At this wavelength, SO2 gas emits strongly. (B) FLIR image of Halemaumau crater lava lake at 11.3 microns. (C) 6-wavelength emissivity spectra of crust and of molten surface on the lava lake. The characteristic drop in emissivity can be seen in the spectrum of molten basalt, a phenomenon which is also observed in laboratory spectra of molten basalts.