THEMIS ROTO IMAGES: A UNIQUE OFF-AXIS DATASET FOR DETERMINING SURFACE ROUGHNESS CHARACTERISTICS

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Introduction:

Quantitative measurements of surface roughness are critical to many aspects of planetary science, including geological and geomorphological studies, volcanological evolution, surface compositional analysis, and assessment of potential future landing site locations [1]. The scale of surface roughness characterization is primarily limited by the wavelength range and spatial resolution of the remotely acquired data. On planetary surfaces, roughness below the spatial resolution of the data produces temperature heterogeneities that alter the spectral morphology of thermal infrared (TIR) emission spectra [1,2,3]. If significant enough, these heterogeneities can produce a negative slope toward longer wavelengths following the separation of emissivity and temperature from the radiance data. It is this spectral slope that can adversely impact any subsequent compositional analysis. This spectral distortion is perhaps most apparent in emission data from very rough extrusive volcanic surfaces. High effusion rates combined with the pre-existing topography can emplace lavas with a large range of surface roughness (similar to that of ‘a’a basaltic textures on Earth). The magnitude of this anisothermal effect on the emission spectrum of any given pixel is directly proportional to the degree and distribution of local topographic slopes in that pixel, which is a function of the spatial resolution of the instrument [2,3]. Work by Bandfield and Edwards (2008) and Bandfield (2009) demonstrated that TIR spectral slopes can be used to quantitatively characterize subpixel surface roughness [4,7]. Furthermore, in addition to anisothermal surfaces, increases in the viewing angle from nadir also affects the measured emissivity of the surface in somewhat similar ways by increasing the areal percentage of thermal shadowing [2,5,6-8].

Methods:

TIR emissivity spectra were collected using two instruments: a custom-designed, field-based system – the Miniature Multispectral Thermal Camera (MMT-Cam) [10], and a laboratory-based interferometer – a Nicolet 670 Fourier Transform infrared Spectrometer (FTIR). The MMT-Cam instrument has one open broadband port and six TIR wavelength bands in the 8 to 12 µm, covering similar regions to both the Earth-orbiting Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) and the Mars-orbiting THEMIS instruments. Emissivity data were acquired with the MMT-Cam at nadir and 21° off-nadir viewing angles, a similar geometry to the THEMIS ROTO data. This was accomplished by measuring the tilt of the instrument relative to the sample surface (tilting the camera nadir and off-nadir). This configuration tests the spectral change with emission angle.

FTIR emissivity data were collected using a custom-built sample stage that allows for angular measurements of the sample. Using this stage, the sample is rotated in 3-degree increments around the central plane, resulting in the same surface being imaged in both nadir and off-nadir viewing geometries. The spot size of the spectral acquisition was approximately 1.5 cm. To approximate directional heating of natural surfaces from solar insolation, the samples were heated for 30 minutes using a Dewalt® D26960 heat gun, set at 510°C and mounted at 45-degrees to the sample surface. The distance from the sample to the guns exhaust port was approximately 20 cm.

The samples chosen for this study are vesicular Hawaiian glassy basalts that exhibit varying degrees of surface roughness from pahoehoe to ‘a’a, as well as a sample of high-silica obsidian glass for comparison. The rough and smooth samples were collected during prior field campaigns from the Mauna Ulu flow field, Hawaii. The obsidian sample was obtained from Mono Domes, California. All samples are archived at the University of Pittsburgh Image Visualization and Infrared Vibrational (IVIS) laboratory archive.

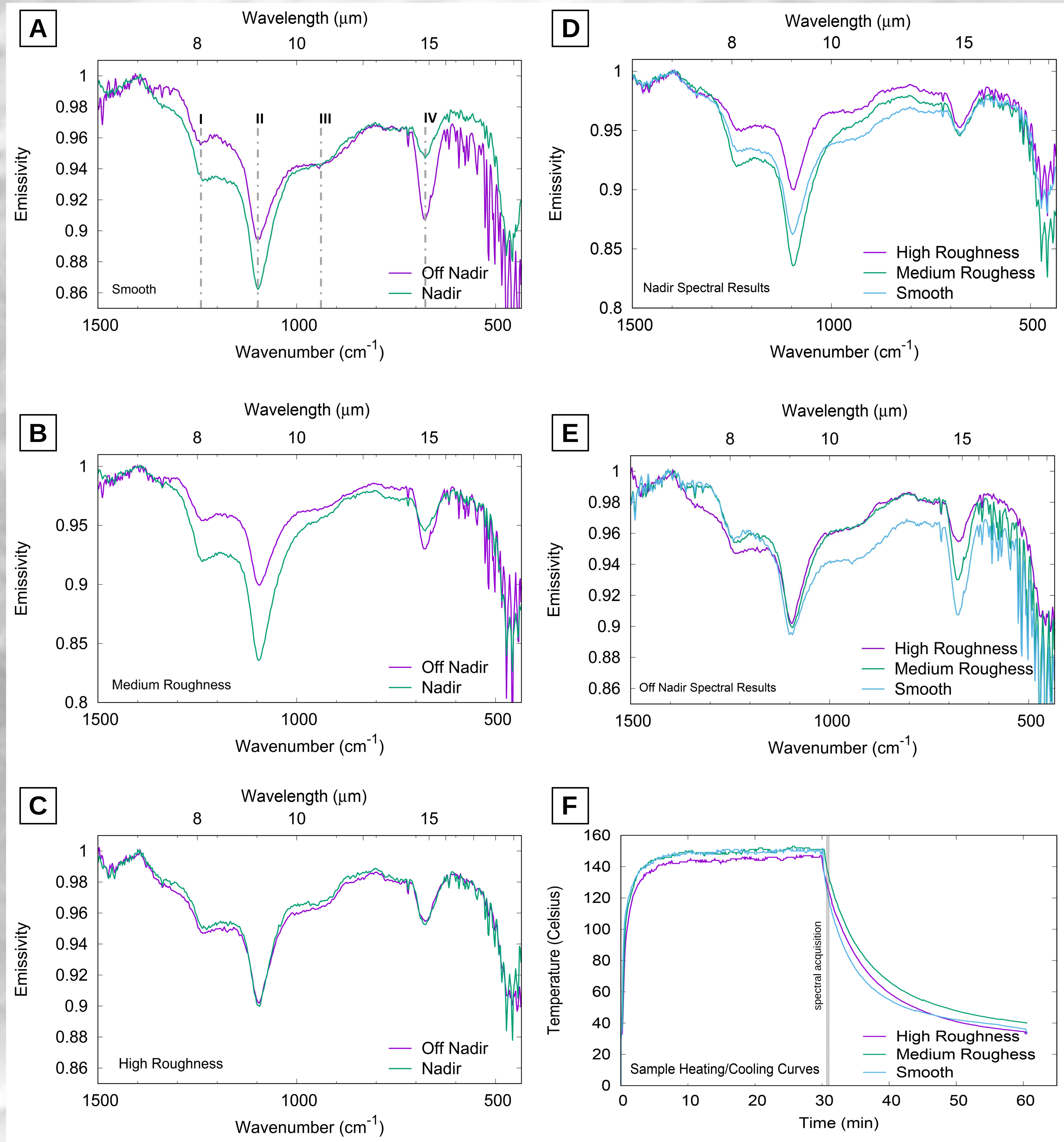

Figure 1. (A-C) FTIR emissivity results for smooth, medium and highly rough basalt samples showing spectral differences between off nadir and nadir-viewing geometries. Spectral features described in the text are labeled I-IV, vertical lines indicate the spectral centers of each feature. **(D&E)** Spectra from each roughness category, showing spectral changes between samples of varying roughness from nadir and off nadir viewing geometries. **(F)** Heating and cooling curves for the three sample morphologies showing an exponential cooling curve. The majority of heat loss and gain occurs in the first five min of heating/cooling. The shaded box shows the period of spectral acquisition.

References:

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Results:

The TIR emission spectra show dominant features at 1240 cm^{-1} (8.1 µm), 1097 cm^{-1} (9.1 µm), and 675 cm^{-1} (14.8 µm). A less obvious broad shoulder is also present centered around 950 cm^{-1} (10.5 µm). These features are labeled I-IV (Fig. 1, A-E). Each of these features was found in both the smooth, medium rough, and highly rough samples and also present in both viewing geometries. A decrease in spectral contrast is observed in the smooth and medium roughness off-nadir viewing geometries compared to nadir (Fig 1 A,B). However, the spectral features of the highly rough sample are generally more muted in all spectra and show little change in spectral contrast between viewing geometries (Fig. 1C). Interestingly, the medium roughness sample shows stronger I and II features compared to the smooth sample, but a diminished III feature (Fig. 1D). Comparing the three nadir spectral results, changes in spectral contrast due to the change in roughness are apparent. In contrast, the off-nadir results show little difference in spectral contrast. Little change in the strength of spectral feature II is observed, but a reduction in the depth of features I, III, and IV is present.

Heating and cooling curves for all three samples are shown (Fig. 1F). Both the heating and cooling follow exponential change in temperature with time. Each sample gains and loses heat within the first 5 min of heating and cooling, attesting to the relatively low thermal inertia of these vesicular samples.

Discussion:

The spectral features identified above have been previously investigated in samples of glassy Hawaiian basalts by numerous authors. Generally, spectral features are typically subdued in ‘a’a vs. pahoehoe [9] (Fig 1 A-C). Features I, III and IV have been attributed to the presence of an accreted silica rich rind or coating indicating the samples have undergone some degree of weathering [9,10], with feature IV being linked to Al-O vibrations [10]. Feature II is indicative of primary stretching vibrations within the silica tetrahedra of the glass structures, this feature tends to shift towards shorter wavelengths with age as the glass becomes more polymerized [9]. Additionally, features II and III are more dominant in pahoehoe systems [9]. The III feature is typically found between 10 and 12 microns and is more dominant in fresh pahoehoe surfaces with a well-developed chill crust. As these flows age, weather, and devitrify; this feature diminishes, and the II feature becomes more pronounced.

Examining the spectral results with respect to the viewing geometry reveals that changes in emission angle results in a decrease in spectral contrast for the smooth and medium roughness samples (Fig. 1 A,B,D,E). This is interpreted as an effect of the apparent “roughness” of the sample. With off-nadir viewing geometries appearing rougher in comparison to nadir due to an increase in reflection and scattering. The high roughness sample shows roughness elements on a scale similar to that of the spot size for these acquisitions (1.5 cm). This effect results in both the nadir and off-nadir viewing geometries appearing equally “rough” with minimal spectral change (Fig. 1C).

Conclusions:

Anisothermal heating of glassy Hawaiian basaltic samples with varying degrees of roughness results in changes to their emissivity spectra. The degree of this changes is dependent on their surface morphology and the viewing geometry. Viewed from nadir and off-nadir geometries, the surface morphology plays a more dominant role resulting in samples of various textures appearing spectrally “rougher” than they are. Additionally, viewing geometry may increase the degree of spectral slope [4,7,8]. Further investigation is ongoing to investigate the slope effect produced in hyperspectral data from anisothermal mixing vs. the role of the viewing geometry.