

THE FAILURE OF THE IMMUTABLE EMISSIVITY ASSUMPTION. Michael S. Ramsey¹ and Alan R. Gillespie², ¹Department of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260, mramsey@pitt.edu; ²Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195.

Introduction: Infrared emissivity is a fundamental property commonly used to identify the composition of planetary surfaces and atmospheres [1]. Numerous detection and mapping methods were developed over the years that rely on mineral spectral libraries as truth in order to identify these constituents in orbital thermal infrared (TIR) datasets [2-3]. For many common scenarios, this approach works assuming the complicating factors and model limitations are well understood. Here, we explore a subset of the vast array of situations where emissivity can no longer be assumed constant and the use of spectral libraries to map planetary surfaces could produce incorrect results.

Background: For a blackbody material with an emissivity of unity at all wavelengths, the emitted radiance follows a Planck distribution, and therefore is the maximum possible for a given temperature. However, vibrations in the atomic structure of most materials give rise to discrete wavelengths where the emissivity is less than one. Emissivity therefore can be defined as the fractional representation of the amount of energy emitted from a surface at a given temperature compared to the energy from a blackbody at that same temperature. These absorption bands have been used for decades to identify the constituents of the emitting surface whether in the laboratory, in the field, from air, or from orbit. Over the years, numerous modeling approaches have also been developed to deconstruct the emissivity measurement in order to extract other properties such as compositional mixing, grain size of the surface, and thermal inertia [4-5]. The fundamental assumption in all these models is that emissivity, when measured accurately, is unchanging. However, this has been shown not to be true for certain situations and in fact may not be strictly true for many remote measurements.

Furthermore, complications arise when trying to measure emissivity uniquely because of the need to know the surface kinetic temperature. This measurement dilemma has been overcome to a large degree in the laboratory by techniques such as detailed calibration, measurements at two temperatures, or measuring the infrared reflectance, which is inversely related to the emissivity and much less dependant on temperature. Separation of temperature from emissivity is subject to greater inaccuracies in remotely acquired data where neither the surface temperature nor the atmosphere is known precisely.

Complicating factors that can dramatically alter the emissivity spectrum of common minerals include

coatings, temperature gradients, and particle-size variations (all very common in planetary applications). More recently, μm - or larger-scale surface roughness resulting in sidewelling emission and cavity radiation has also been shown to decrease the contrast of the spectral absorption features [6-8]. For measurements made over thermally heterogeneous surfaces, non-linear mixing of temperatures will greatly alter the emissivity spectrum, making both quantitative analyses and accurate correction nearly impossible without sophisticated thermal and compositional deconvolution algorithms [9].

Approach: For the past decade, the authors have been exploring numerous scenarios that affect the emissivity of natural surfaces. For example, research into the response of emissivity with homogeneous temperature changes shows dramatic variability occurs with a change of state (i.e., a structural phase change or state change as the material begins to melt) [10]. Surfaces with heterogeneous temperature mixing or non-unity emissivity can produce similar errors in the retrieved emissivity but for very different reasons. In addition, much more subtle changes may arise even at lower temperatures, calling into question the accuracy and interpretability of emissivity at the percent level.

Conclusions: We give an overview of the current state of knowledge of how emissivity can be measured and where incorrect assumptions may lead to inaccurate interpretations of the data, for example in estimating roughness or mineral abundance. Although it is more common for library minerals to be missed entirely due to poor spectral contrast, it is also possible that one mineral could be misidentified for another, especially in extreme conditions such as the very high temperatures encountered at active lava flows.

References: [1] Bandfield, J. L. et al. (2000) *Science*, 110, 1626-1630. [2] Christensen, P. R., et al. (2001) *JGR*, 106, 23873-23885. [3] Rodgers, A. D. et al. (2007) *JGR*, 112, E02004. [4] Ramsey, M. S. and Christensen, P. R. (1998) *JGR*, 103, 577-596. [5] Ruff, S. W. and Christensen, P. R. (2002) *JGR*, 107, no. 10.1029. [6] Bandfield, J. L. (2009) *Icarus*, 202, 414-428. [7] Ramsey M. S. and Fink, J. H. (1999) *Bull. Volc.* 61, 32-39. [8] Danilina, I. (2011) *Ph.D. Dissertation, Univ. of Washington*. [9] Rose, S. R. et al. (2013) *RSE*, (in press). [10] Lee, R. J. et al. (2013) *JGR*, (in review).

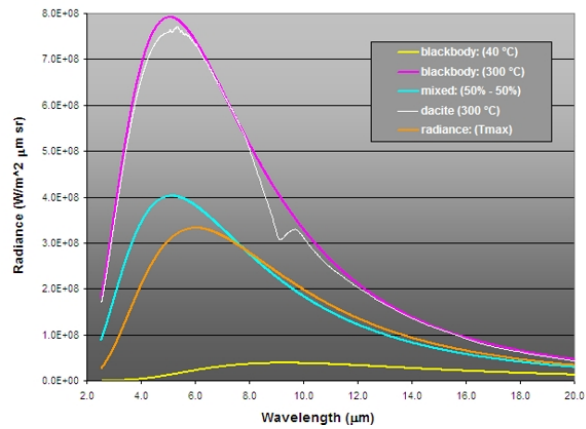


Figure 1. Thermal infrared blackbody radiance curves and a dacite (white spectrum) showing the spectral absorptions at ~ 5.2 and $9.2 \mu\text{m}$. If surface elements are at two temperatures (e.g., 40°C and 300°C), the resulting radiance no longer follows Planck behavior (orange vs. cyan spectrum). This non-linearity results in errors to the retrieved emissivity because of the Planck behavior assumption (Figure 2).

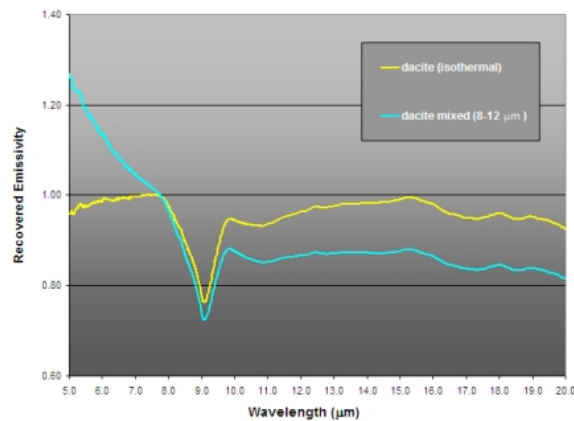


Figure 2. Spectral retrievals of the dacite sample (Figure 1). Yellow spectrum is derived from an isothermal sample and shows an accurate retrieval with maximum emissivity values near unity and the correct depth of the main absorption feature. Cyan spectrum is derived from a non-isothermal sample similar to the mixed spectrum shown in Figure 1. Note the lower than expected emissivity at longer wavelengths. A similar emissivity depression can be caused by the "Planck Effect," which results in the recovered broadband emissivity changing with temperature if the spectral emissivity at discrete wavelengths is not constant.

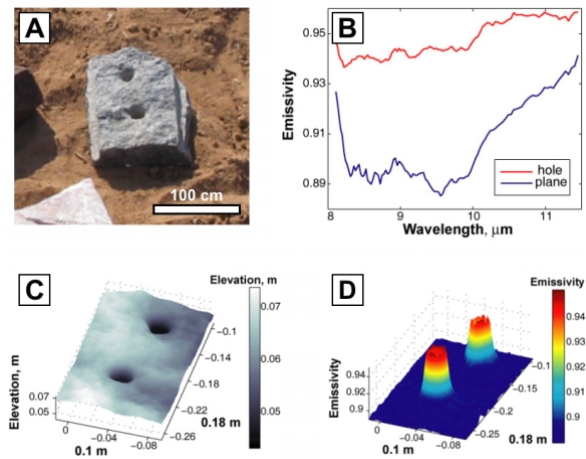


Figure 3. Impact of surface topography on derived emissivity. [A] Norite rock with two drilled holes. [B] Field-based emissivity spectra of the rock using a TELOPS Inc. HgCdTe imaging spectrometer (note the reduction in spectral contrast). [C] Micro digital elevation model (DEM) of the rock's upper surface. [D] Change in the derived emissivity due to the blackbody effect is readily modeled [8].

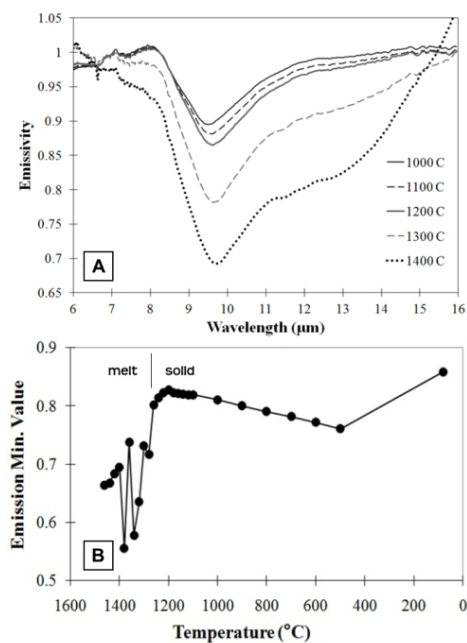


Figure 4. Results from the in-situ melting and laboratory spectral acquisition of a synthetic glass mixture (Ab50 + Qtz). [A] With increasing temperature, the emissivity is depressed by more than 35%. [B] The emissivity minimum value follows a linear increase with temperature until near the liquidus temperature ($\sim 1350^\circ\text{C}$) [10].