Spectral Thermal Emission of the Lunar Surface: Implications for Mapping of the Surficial Volatiles and Monitoring Variations with Time of Day. J.-Ph. Combe[1], P. O. Hayne[1,2], D. Paige[3] and T. B. McCord[1]. [1]Bear Fight Institute, Winthrop, WA, jean-philippe_combe @ bearfightinstitute.com. [2]Caltech, Pasadena, CA. [3]UCLA, Los Angeles, CA.

Introduction: The thermal emission of the surface of the Moon has measurable effects beyond 2.2 µm for temperatures above 250 K [1]. Therefore, the thermal contribution is key information for the characterization and mapping of the composition from reflectance spectra. This is especially relevant for – but not limited to – the absorption bands at 2.8 and 3 µm of the hydroxyl group which has been discovered by the Moon Mineralogy Mapper (M^3) onboard the Chandrayaan-1 spacecraft [2-4] and confirmed by the Epoxi mission [5] and Cassini Visual and Infrared Mapping Spectrometer (VIMS) [6]. The broad absorption band of pyroxenes around 2 µm is also affected by thermal emission [7].

Because the thermal correction of M^3 reflectance spectra relies on measurements where absorption bands occur [1], the surface temperature may be underestimated or even impossible to determine where the 3-µm absorption band is strong. In order to improve absorption band depth calculation beyond 2.2 µm, independent evaluation of the thermal contribution is needed. Such data are now available from the Diviner Lunar Experiment Radiometer [8] onboard Lunar Reconnaissance Orbiter (LRO).

This study is a thermal correction comparison using both M^3 and Diviner data, applied on the Ryder crater area (Fig. 1a, b), which is a rare occurrence on the Moon where a strong 3-µm absorption band exists while the surface is well-illuminated. Results include 1) a comparison of M^3 and Diviner temperature measurements, 2) an analysis of the effects of the correction on the 3-µm absorption band and 3) an evaluation of the variations of the 3-µm absorption as function of lunar local time of day.

M^3 and Diviner observations:

Reflectance from M^3. M^3 was an imaging spectrometer in lunar orbit, designed to map the surface reflectance in the range 0.4-3 µm [9]. The mission has been organized into two optical periods (OP1 and OP2) [10]. 85 wavelength channels were used in global mapping mode, with spatial resolution ranging from 140 m/pixel (OP1) to 280 m/pixel (OP2). M^3 observed also targeted areas with 260 wavelength channels and at higher spatial resolution (~70 m/pixel during OP1 and ~ 140 m/pixel during OP2). OP1 corresponds to morning illumination, while in OP2 the lunar local time of the observed surfaces was in the afternoon for a large part, and around noon for the rest. During the whole mission, which ended in late August 2009, a global mapping campaign achieved ~85% coverage.

Brightness temperature from Diviner. Diviner is a multispectral imager that observes the surface of the Moon in the range 0.3 to 400 µm using 9 channels, mostly from the nadir. Off-track observation is possible on special request. Images are 21 pixels wide. Brightness temperature is measured between 8 and 400 µm using six channels. Precession of the LRO orbit allows Diviner to gradually build up time-of-day coverage at each location on the Moon, while operating in the nominal nadir-pointing mode.

Selection of M^3 and Diviner data: In order to perform a thermal emission correction of M^3 spectra, Diviner temperatures have to be available for the same area, and the closest time of day possible to M^3 observations. Lunar local time of day is calculated from latitude, longitude, solar incidence and azimuth, assuming the Moon is a sphere. This information is contained in the backplanes (LOC and OBS files) provided with any M^3 radiance file [10]. For the Ryder Crater area, Diviner observations to date occurred earlier in the day than M^3 observations. The difference in lunar local time between Diviner and M^3 observations is within 15 mn (Moon time), which is ~7 terrestrial hours. Future targeted observations by Diviner will minimize this discrepancy for Ryder crater and other regions of interest.

Temperature calculation: *From M^3 reflectance spectra.* The lunar surface temperature is <400 K. Maximum emission typically occurs at wavelengths longer than 10 µm, well beyond the range observed by M^3. Temperature estimates from M^3 assume any lunar spectrum without thermal contribution has a continuum shape that can be modeled by a straight line beyond 1.5 µm. The temperature is iteratively calculated, using Planck's law, from the difference between the M^3 spectrum and the idealized continuum at 2.7 µm. Details of the method are described in [1].

From Diviner. For this study, we used temperature derived from the channel at 13 µm. Brightness temperature depends on the solar incidence angle, the time the surface has been illuminated and heated before the observation, and surface emissivity. The geometrical parameters are controlled by the lunar local time of day, latitude, and local slope. Emissivity is a property of the surface that depends on the mineralogical composition and surface roughness within the area covered by one pixel. This implies a given area has mixed surface temperatures.

Calculation of the 3-µm absorption band depth: The center position of this absorption is just beyond the longest M^3 wavelength. This implies the band depth calculation has to rely on an extrapolation of a continuum. This continuum is assumed to be linear between two anchor ranges (1.419 – 1.528 µm and 2.497 – 2.736 µm respectively), and extrapolated in the range 2.896 – 2.936 µm where both the continuum and the M^3 spectrum are averaged. The band depth is: 1 - Spectrum/Continuum [3]

Difference of temperature estimates between M^3 and Diviner (Fig. 1 c, d): Negative temperature differences occur at the edges of areas where temperatures cannot be estimated with M^3 because of the presence of a strong 3-µm absorption band. Surface temperatures retrieved from M^3 are sometimes higher (< 20K) than Diviner measurements. This occurs where the 3-µm absorption is weak or inexistent. Because the difference in lunar local time between Diviner and M^3 observations, and because M^3 is more sensitive to the highest temperature component in a mixed-temperature scene, the temperature derived from M^3 is expected to be higher than the temperature of the surface derived from Diviner.

Maps of the 3-µm absorption band – Discussion: Whether thermal removal is derived from M^3 or Diviner implies a difference in the 3-µm absorption band depth estimate (Fig. 1e). The maximum difference is ~0.02 at 9 h and ~0.05 at 13 h, which is 10 to 20% of the maximum band depth in this area. These values are an indication of the underestimation implied from M^3-derived temperatures, which emphasizes the need for more reliable temperature measurements such as done by Diviner. As shown on Fig. 1e, in average the band depth is stronger at 9 h than at 13 h (~0.03 difference). From 9 h to 13 h there is a decrease of the absorption band in the sun-facing slopes. Little differences exist between the interior of Ryder and adjacent areas. A small decrease of the band depth is observed between 9 h and 13 h. Given the small area that could be analyzed for this comparison and the limited data processed so far, it is still unclear whether this observation indicates actual variations of surface volatile abundance with time of day. The main uncertainty at the present time is that Diviner and M^3 are not sensitive to the same surface temperatures, which may result in thermal correction of M^3 data that are not fully appropriate.

Perspectives: Possible variation of the surface content in volatiles with lunar local time of day is a motivation for a more extended investigation. New Diviner measurements have been already requested for areas: 1) observed simultaneously by M^3 and Diviner and 2) at two different times of day (at least). On the other hand, global map of temperatures at any time of day will be eventually available from a model [8]. However, for accurate modeling of the thermal emission, the surface roughness will be also considered. Eventually, the model will also account for the topography.

References:

[1] Clark et al. (a) submitted to JGR. [2] Pieters et al., Science 326, 2009. [3] McCord et al., submitted to JGR. [4]Clark et al. (b) submitted to JGR. [5] Sunshine et al., Science 326, 2009. [6] Clark, Science 326, 2009. [7] Clark et al., Icarus 40, 1979. [8] Paige et al. Science 330, 2010. [9] Green et al., submitted to JGR. [10] Boardman et al., submitted to JGR.

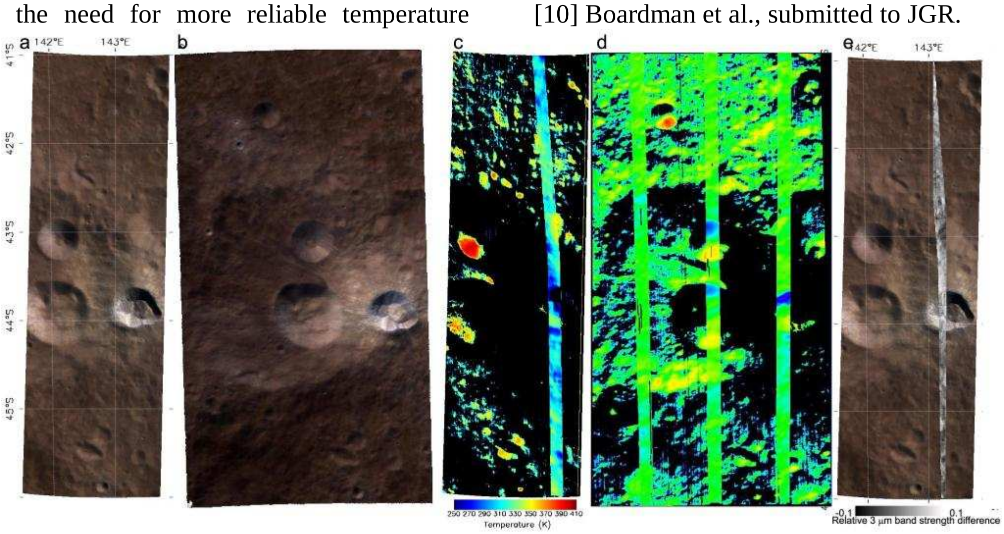

Figure 1.a,b: M^3 observation of Ryder crater with morning illumination (a: 9 h local time) and afternoon illumination (b: 13 h local time). c, d: Surface temperatures derived from Diviner with M^3-derived temperatures in the background. e:Difference of the relative 3-µm band strength.