LUNAR SURFACE HYDRATION ESTIMATION OVER COMPTON-BELKOVICH VOLCANIC COMPLEX (CBVC) REGION USING CHANDRAYAAN-2 IIRS OBSERVATIONS.

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Introduction: The Moon Mineralogy Mapper (M^3) on-board ISRO's Chadrayaan-1 has changed our perspectives on Moon [1-3]. Prior to the availability of M^3 observations Moon was believed to be anhydrous and considered to be bone dry. However, the hyperspectral observations from M^3 significantly helped in the detection of widely distributed hydration signatures across the lunar higher latitudes [1-3] and at several other places locally. Hydrated nature of the lunar interior has also been confirmed by recent *in situ* measurements of lunar melt inclusions and lunar apatites suggesting heterogeneous distribution of water in the lunar mantle [4-6]. Enhanced hydration has also been reported recently from Compton-Belkovich Volcanic Complex (CBVC) [7, 8] and central peaks of Bullialdus [9] and Theophilus [10] craters that hint towards the presence of a hydrous lunar mantle. Telescopic observations from SOFIA also confirmed the presence of water in the Clavius crater based on the detection of a strong 6-µm emission band [11].

The hydration signature appears as an absorption feature in the 2.8-3.5 μm spectral region of the electromagnetic spectrum arising due to the presence of hydroxyl (OH) groups attached to a metal cation or molecular water (H_2O), or a combination of the two [2]. The radiance observations in this region of the spectrum are contaminated with thermal emission. For precise estimation of the hydration content the radiance measurements need to be corrected for this thermal emission. However, this thermal correction is not straight forward. It requires the knowledge of lunar surface temperature and emissivity.

The Imaging InfraRed Spectrometer (IIRS) on-board Chandrayaan-2 has extended spectral range up to 5.0 μm. The observations in the extended range can be used for the thermal correction of the spectral observations in the 2.8-3.5 μm range. In this study we have used the 3-5 μm observations from IIRS to estimate lunar surface temperature which in turn is used for the thermal correction of the IIRS observations in 2.8-3.5 μm range. The hydration content estimation in the Compton-Belkovich complex region is performed using the thermally corrected IIRS observations.

Methodology: The lunar surface temperature (T_s) is retrieved using the 3-5 μm IIRS observations. The retrieval is performed via optimal estimation [12]. The lunar surface spectral emissivity (ϵ_λ) is calculated using the following relationship

$$\epsilon_\lambda = \frac{I_\lambda - R_\lambda}{B(\lambda, T_s) - R_\lambda} \qquad (1)$$

where, I_λ is the IIRS observed radiance at wavelength λ, T_s is the surface temperature

$$R_\lambda = \frac{J_\lambda}{\pi d^2}\frac{2cos(\theta)}{cos(\theta)+cos\,(e)} \text{ and } B(\lambda, T_s) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k T_s}}-1}$$

J_λ is the spectral solar irradiance at wavelength, d is the mean Sun-Moon distance in astronomical units, θ is the incidence angle, e is the emergence angle, h is the Planck's constant, c is the speed of light, and k is the Boltzmann constant.

Once the spectral emissivity is available the thermal contribution ($\epsilon_\lambda B(\lambda, T_s)$) to the radiance observation is calculated and subtracted from the IIRS observation to obtain the thermally corrected radiance which is then converted to reflectance.

The reflectance spectra are then converted to single scattering albedo using the following Hapke radiative transfer equation [13]:

$$r_\lambda = \frac{\omega_\lambda}{4\pi}\frac{\mu_0}{\mu_0+\mu}\{[1+B(g)]P(g) + H(\mu_0, \omega_\lambda)H(\mu, \omega_\lambda) - 1\} \qquad (2)$$

In Eq. (2) r_λ and $\omega_\lambda$are the spectral reflectance and the single scattering albedo respectively, at wavelength λ. μ_0 and μ are the cosine of incidence and emergence angle respectively. The function H accounts for the multiple scattering and is given as

$$H(x) = \frac{1}{1-(1-\gamma)x\left[r_0 + \left(1 - \frac{1}{2}r_0 - r_0 x\right) ln\,\left(\frac{1+x}{x}\right)\right]}$$

where, $\gamma = \sqrt{1-\omega_\lambda}$ and $r_0 = \frac{1-\gamma}{1+\gamma}$. Here, we have assumed isotropic scattering (P=1) and no backscattering (B=0). With this assumption the above Eq. (2) reduces to

$$r_\lambda = \frac{\omega_\lambda}{4\pi}\frac{\mu_0}{\mu_0+\mu}H(\mu_0, \omega_\lambda)H(\mu, \omega_\lambda) \qquad (3)$$

The above Eq. (3) is solved for ω which in turn is used for the estimation of effective single-particle absorption thickness (ESPAT) at wavelength 2.85 μm [14]:

Results: Enhanced hydration of magmatic origin has been observed over a number of lunar pyroclastic deposits [14] challenging the longstanding belief that the lunar interior is anhydrous. In fact, quantitative water maps have been obtained based on thermally corrected M^3 data from Chandrayaan-1 mission. As already discussed, hydration signatures were previously reported from the Compton-Belkovich volcanic complex [7, 8], an ash flow collapsed caldera on the Moon [16] that is believed to have formed due to the silicic explosive volcanism [17].

The thermally corrected radiance along with the observed radiance is shown in Fig. 1. The plot clearly shows the contribution of the thermal emission beyond 2.5 μm. We have used Hapke's ESPAT parameter to quantify the amount of hydration present at the CBVC following the methods described by [14]. The distribution of ESPAT estimated using the thermally corrected IIRS observations in shown in Fig. 2. The ESPAT value ranges from 0 to 0.05 which matches well with Li and Milliken estimates [15] shown in Fig. 3.

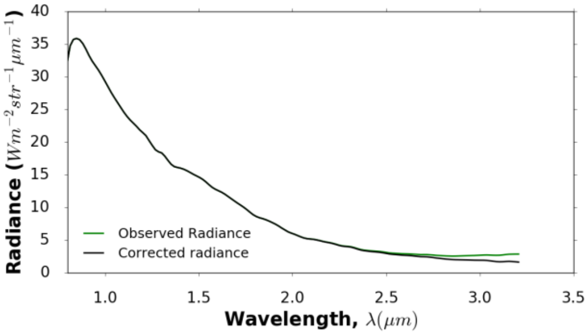

Figure 1. A sample plot of the observed IIRS radiance spectra along with the corresponding thermally corrected spectra.

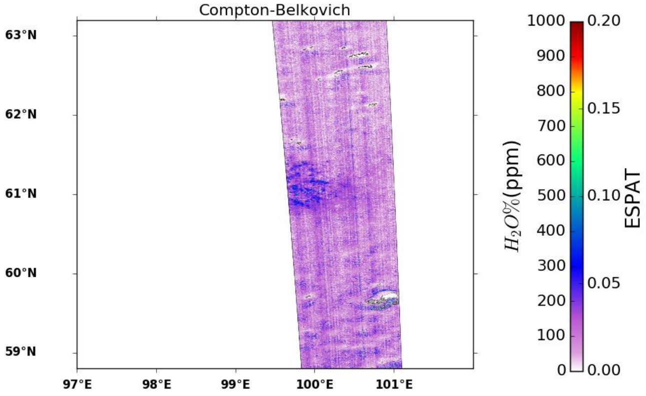

Figure 2. Spatial distribution of the ESPAT over the Compton-Belkovich complex region, estimated using the thermally corrected IIRS radiance.

Estimated water content at Compton-Belkovich is found to range from ~200 to 250 ppm, relative to the surrounding terrains having background water content in the range of ~50-100 ppm.

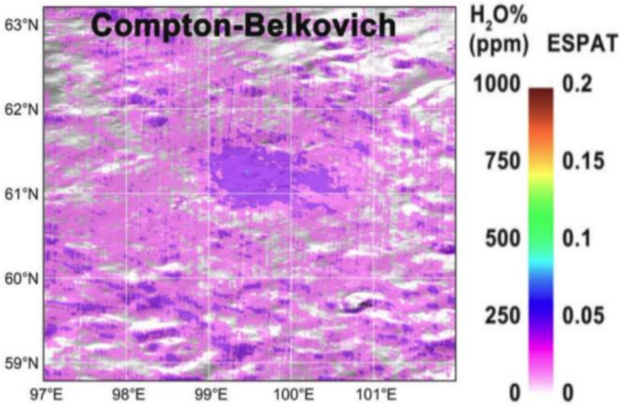

Figure 3. Spatial distribution of the ESPAT over the Compton-Belkovich complex region, obtained from Li and Milliken [15].

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