LUNAR REGOLITH PROPERTIES CONSTRAINED BY LRO DIVINER AND CHANG'E 2 MICROWAVE RADIOMETER DATA. J. Feng[1], M. A. Siegler[1], P. O. Hayne[2], D. T. Blewett[3], [1]Planetary Science Institute (1700 East Fort Lowell, Suite 106 Tucson, AZ 85719-2395, jfeng@psi.edu), [2]University of Colorado, Boulder. [3]Johns Hopkins Univ. Applied Physics Lab, Maryland.

Introduction: The geophysical properties of the lunar regolith have been well-studied, but many uncertainties remain about their in-situ nature. Diviner Lunar Radiometer Experiment onboard LRO [1] is an instrument measuring the surface bolometric temperature of the regolith. It has been systematically mapping the Moon since July 5, 2009 at solar and infrared wavelengths covering a full range of latitudes, longitudes, local times and seasons. The Microwave Radiometer (MRM) carried by Chang'e 2 (CE-2) was used to derive the brightness temperature of the moon in frequencies of 3 GHz, 7.8 GHz, 19.35 GHz and 37 GHz. During its 7-month operation period, CE-2 MRM obtained about 7.8 million records.

Here, we use MRM to extend our understanding of Diviner surface measurements and use Diviner to correct some calibration errors within the MRM dataset. The brightness temperature is essentially an integral of physical temperature of regolith up to a certain depth based on a weighting function. With their different wavelengths, Diviner and MRM sense different depths in the regolith. The combination of these two data sets can provide new constraints on the thermal and electromagnetic properties of the lunar regolith.

Data set: To match the spatial resolution of CE-2 MRM (17.5 km @ 7.8 GHz, 19.35 GHz and 37 GHz, 25 km @ 3 GHz), we select the 2-ppd Global Cumulative Products of Diviner. Also, a slope map with the same resolution is created by using the Digital Elevation Model (DEM) from the Lunar Orbiter Laser Altimeter (LOLA). The Diviner and MRM data in the region were constrained to slopes smaller than 1.5° to exclude the influence of topography on the temperature. In order to simplify the radiative transfer model and derive a general dielectric loss of the regolith, we only analyze the region in the low-Titanium highlands. The 1064-nm normal albedo map made by LOLA and FeO and TiO_2 map produced by LOLA and Clementine are used to distinguish mare and highlands.

Approach and Methods: To study the geophysical properties, it is necessary to develop a theoretical model including these parameters to fit both the diurnal variation of Diviner and MRM data of the global moon.

Our model consists of two parts: one is a one-dimensional thermal model and the other is a microwave radiative transfer model. The thermal model is described in detail by [2, 3] and the microwave model is built based on the method proposed by [4]. The results of the thermal model (which includes layer numbers, layer thickness, temperature profile and density profile) are input parameters for the microwave model.

In contrast to [2, 3], we update the thermal parameters to match the surface temperature at noon in the equatorial region and diurnal temperature variation in high latitude (Fig. 1). The best fit of the data show that for most highlands the regolith has a bond albedo of 0.09 at normal solar incidence and bond albedo at arbitrary solar incidence θ is represented by $A=0.09+0.04\times(4\theta/\pi)^3+0.05\times(2\theta/\pi)^8$. This required change is likely due to the effects of sub-footprint roughness on the effective albedo of the surface [5] which has a larger effect on bolometric temperature than the single wavelength (Diviner channel 7) used in [2].

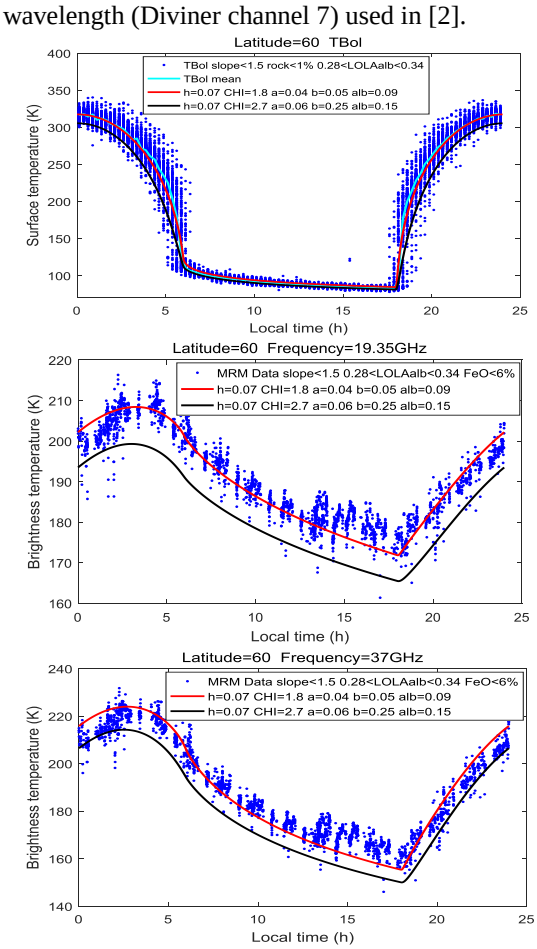

Fig. 1. Top figure shows the Diviner data and two thermal models with different parameters in latitude 60. The black curve represents results from the old parameters.

The figures in the middle and bottom denote the MRM data and microwave models in the same latitude.

The match between the MRM data and the microwave model for all latitudes also requires a tentative adoption of a new radiative conductivity parameter (χ of [2, 3]) of 1.8, which is much smaller than 2.7. The loss tangent of the regolith in highlands is updated to:

$$\tan\delta = 10\text{^}(0.312\rho(z) + 0.0043 \times f/10^9 - 2.621)$$

Where f is the frequency, and $\rho(z)$ is density.

Calibration issue of low frequencies channel: Based on the developed theoretical model, we find that there is a discrepancy between the MRM data and the predicted brightness temperature on 3GHz and 7.8 GHz (Fig. 2 and Fig. 3). The biggest difference appears at around 5 h and 19 h, when the data was collected over the terminator of the Moon.

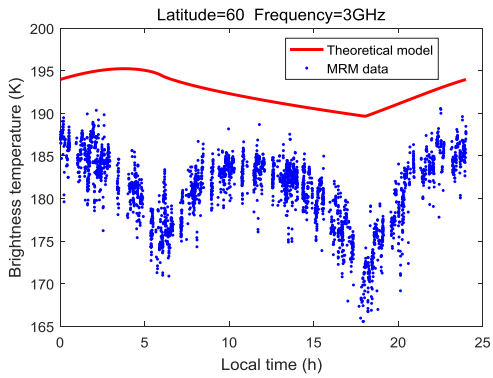

Fig. 2. MRM data on 3GHz and proposed theoretical model

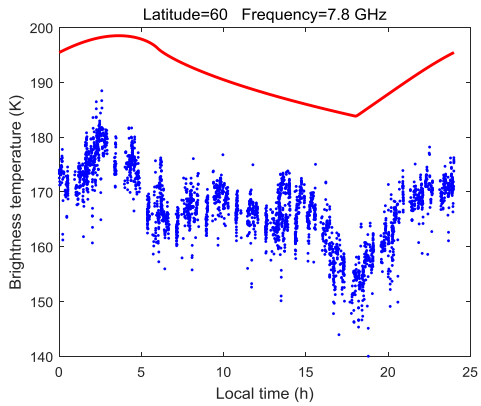

Fig. 3. MRM data on 7.8 GHz and proposed theoretical model

The MRM instrument calibrated itself using a second set of space looking cold horns. Here we illustrate that the 3.0 and 7.8 GHz channel time of day offset is directly related to contamination of this cold horn by the Sun. It can be seen from Fig. 4 that the difference of MRM data and theoretical model is strongly related to the angle between the cold horn and the Sun. In the terminator orbit the x-panel of CE-2 orbiter was facing the Sun in order to reorient the solar panels, which only had a single axis gimbal. This is also the reason CE-1 and CE-2 could not collect push-broom imaging while in a terminator orbit. However, the calibration horn of MRM was installed on the x-panel. Facing the Sun brought extra radiation to the large 3.0 and 7.8 GHz cold horns and lead to a lower calibrated brightness temperature on the Moon.

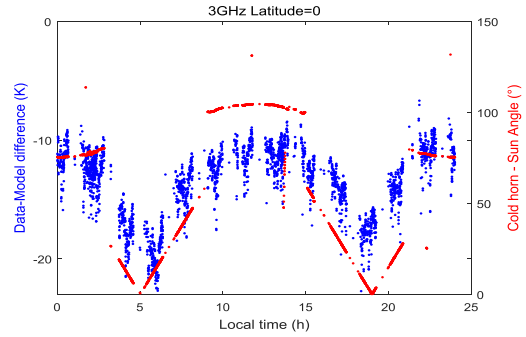

Fig. 4. The difference between MRM data and the model on 3GHz and the angle between the cold horn and the Sun.

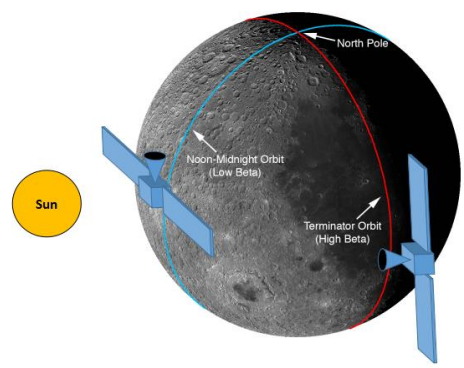

Fig. 5. The attitudes of CE-2 spacecraft in the Noon-Midnight Orbit and Terminator Orbit. The cone illustrates the space-looking cold horn orientation.

Conclusion: We have constructed a theoretical model to simulate the brightness temperature of regolith in highlands on the moon. By using this model to fit both Diviner and MRM data, we derive a new set of parameters to describe the thermal and electromagnetic properties of the regolith in lunar highlands. Analysis of the difference of data and model on low frequencies tells there is a contamination on the calibration horn. The recalibration of data at 3 GHz and 7.8 GHz will be implemented in the future.

References:

[1] Paige, D. A. et al. (2010) *SSR, 150*, 125-160. [2] Vasavada, A. R. et al. (2012) *JGR, 117*, E00H18. [3] Hayne, P. O. et al. (2017) *JGR, 122*, 2371-2400. [4] Ulaby, F. T. et al. (1981) *Microwave Remote Sensing: Active and Passive, Volume I: Fundamentals and Radiometry*, Addison-Wesley Pub. [5] Rozitis, B. and Green, S. F. (2011) *Mon. Not. R. Astron. Soc. 415*, 2042–2062.