Chang'E-1 and Chang'E-2 Lunar Microwave Radiometer Data Analysis and Lunar Subsurface Temperature Profile Modelling.

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Introduction: China's first lunar probe CE-1 was successfully launched on Oct. 24th, 2007 in Xichang, and controlled to impact on the lunar surface On March 1, 2009. After that, The Chang'E-2 (CE-2) probe was launched on October 1, 2010. During its operation period, they obtained a large number of valid scientific data from the eight instruments in its scientific payload, including the Microwave Radio Meter (MRM). The MRM is a 4 frequency microwave radiometer, and it is mainly used to detect the brightness temperature (TB) of the lunar surface, to retrieve lunar regolith thickness, temperature, dielectric constant and other related properties. The MRM has 4 channels working at frequencies of 3.0GHz, 7.8GHz, 19.35GHz and 37GHz with lower frequencies typically having deeper penetration. Details of instruments and ground calibrations are described in ref [1,2]. We proposed a new microwave transfer model to assist with retrieving lunar heat flow and subsurface temperature structure, and both CE-1 and CE-2 data were analyzed.

Method: First, we made an initial analysis of the available data, summarised in a sequence of 3-dimensional Lunar TB map for all the four CE-1 channels (Figure 1). The penetrating depth is expected to be generally less than 0.5 m at 37.0 GHz, 1.0 m at 19.35 GHz, and 2.0 m at 7.8 GHz, and the 3 GHz frequency channel can penetrate to a depth of 5 m [1]. At 5m, temperature variations were expected to be only related to latitude, mineralogy and underground heat flow. Hence the 3GHz (a) map appears to show less variation. For the other channels differences between the maria and highland can be seen, which is likely to be caused by albedo difference and mineralogy difference. As the maria regions have much higher FeO and TiO_2 content, microwave emission is cannot emminate from a deep as in highland regions. Therefore, maria regions would show slightly higher TB in the day as the signal are mainly from layers closer to the surface.

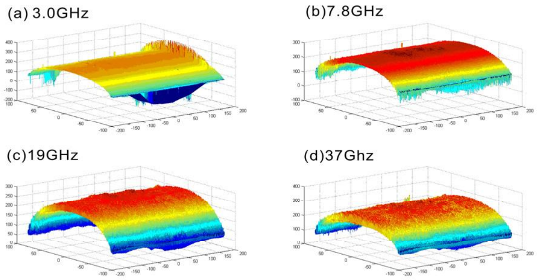

Figure 1. Moon's 3-D brightness temperature map derived from CE-1 MRM's four channel's data.

High resolution CE-2 TB map is also produced below,

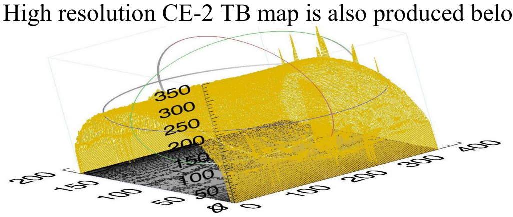

Figure 2. 3GHz TB map derived from CE-2 MRM.

TB contor maps are also produced (Figure 3).

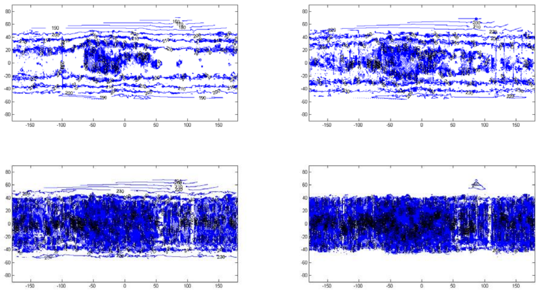

Figure 3. MRM contour image of the TB distribution on lunar surface at lunar day.

A radiative transfer forward model has been derived using fluctuation dissipation theorem to assist with analyzing the the CE-1 and CE-2 MRM data. The forward model was then used invert the measured brightness temperatures to generate subsurface temperature profiles. In both forward and inverse cases one-dimensional thermophysical multilayer models were used. The total number of layer is 6 with the deepest layer at 5m, and with more layers in the top 20cm where the temperature changes most rapidly. The forward model calculates the contribution of each depth on the TB of the Moon (at different frequencies) to understand how deep the MRM channels could penetrate. Conversely, the inverse model derives a 'measured' lunar temperature profile based on the observed TB of the Moon, lunar mineralogy from M3 [3] and complex composition parameters of lunar surface. The proposed model details will be shown in the poster. The model was written in MATLAB.

Results: The forward model results are derived, showing a dependency on the mineralogy with two extremes to be presented here as examples. The value S is defined as the sum of %FeO and $\%TiO_2$. For each location, with its specific S value, the model is used to calculate the contribution from each layer. When S=0, 3GHz signals are mainly from base layer (e.g. very deep penetration, 1m-5m). When s=25, 37GHz signals are mainly from two top layers (e.g. ~10cm).

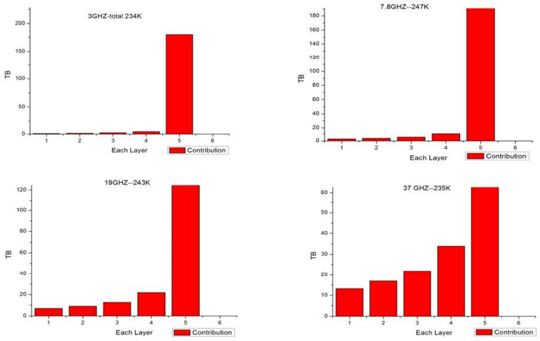

Figure 4. (S=0) Each layer's temperature's weight (contribution) in the MRM TB measurements, with predicted TB marked on the top.

The CE TBs for 3GHz and 7.8GHz are ~234K and 250K, respectively, therefore match well with the presented forward model's prediction.

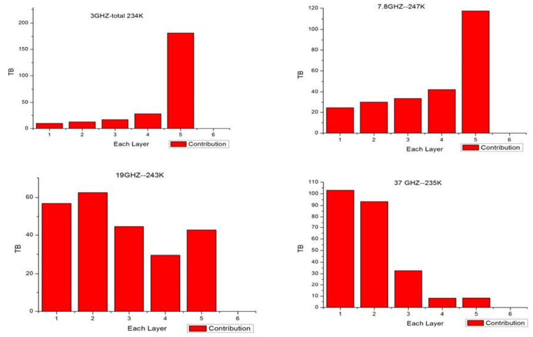

Figure 5. (when S=25) Each layer's temperature's weight (contribution) in the MRM TB measurements.

When using an average value of S=15 for equitorial MRM midday data, a rough average subsurface temperature curve (in the daytime) can be derived and is summarized as Figure 6.

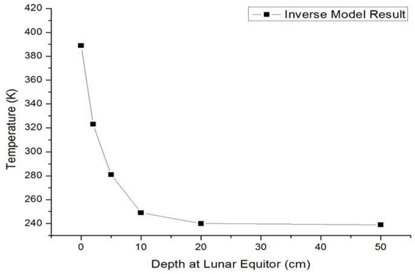

Figure 6. Based on MRM data, my model provided the rough 'measured' mean temperature profile beneath the lunar equatorial surface, at the lunar midday. (The surface temperature is from Diviner. PDS data.)

The lunar soil temperature changes significantly within top 2 cm before stablising beneath approx. 20 cm. Based on standard assumptions for density and heat capacity the stable temperature is around 240K at lunar equator.

Application: Finally, we use an S distribution derived from M3 measurements [3] and apply the model for retrieval variations in subsurface temperature. The 1m depth temperature map from 0 to ±30N, lunar nearside, is shown in Figure 7, with a topographic map in Figure 8,

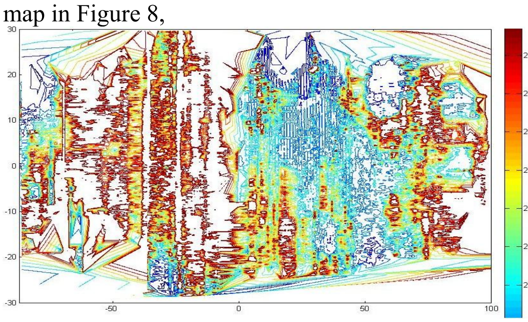

Figure 7. Subsurface temperature of moon at 1m depth.

Figure 8. Corresponding area's shaded relief map [4].

From Figure 7 and 8 we may notice that, different geological structures do have different subsurface temperatures. KREEP terrene including Procellarum has higher subsurface temperature, while the other regions like Crisium and Tranquillitatis etc show lower temperatures. KREEP basalt has about 300 times more uranium and thorium than chondrites, so this implies that a large portion of Moon's heat-producing ements is located within this single crustal province [5].

Discusions: By measuring the internal heat flow and deep subsurface temperature profile of the Moon based on MRM data, we can trace backwards and constrain the lunar core thermal flow, an important result in e.g formation theories of the Moon's crust and any residual activity in its core. Preliminary models and results are obtained, with improvements coming soon.

References: [1] Wang Z Z et al. (2010) *Sci China Earth Sci*, 53, 1392- 1406. [2] Li Y et al. (2010) *Sci China Earth Sci*, 53 (9): 1379–1391. [3] Zhang W and N Bowles (2013), Mapping lunar TiO2 and FeO with Chandrayaan-1 M3 data, 44th LPSC abstract. [4] http://www.lpi.usra.edu/resources/mapcatalog/LMP [5] M A . Wieczorek and R J. Phillips (2000) *J. Geophys. Res,* 105, 20417-20430.