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Chang'E Lunar Microwave Radiometer Data Analysis and Lunar Subsurface Temperature Profile Modelling

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Abstract

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.

1. 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, both missions 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].

2. Methods

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 cannot emminate from as deep as in highland regions. Therefore, maria regions would show slightly higher TB in the day as the signal is mainly from layers closer to the surface.

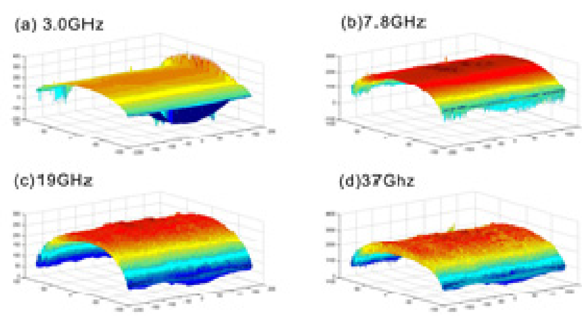

Figure 1: Moon's 3-D brightness temperature map derived from CE-1 MRM's four channel's data.

A radiative transfer forward model has been derived using fluctuation dissipation theorem to assist with analyzing both the CE-1 and CE-2 MRM data. The forward model was then used to 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 layers in the model 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 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 including density profile distribution. The model was written in MATLAB.

3. Results

Example forward model calculations are used to show the dependency on the mineralogy with two extremes (Figure 2).. 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).

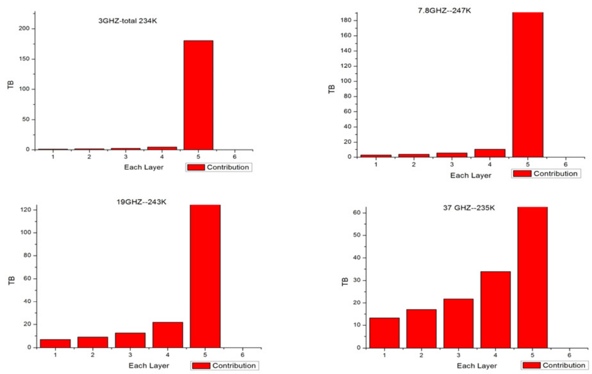

Figure 2: (S=0) Each layer's temperature's weight (contribution) in the MRM TB measurements, with predicted TB marked on the top.

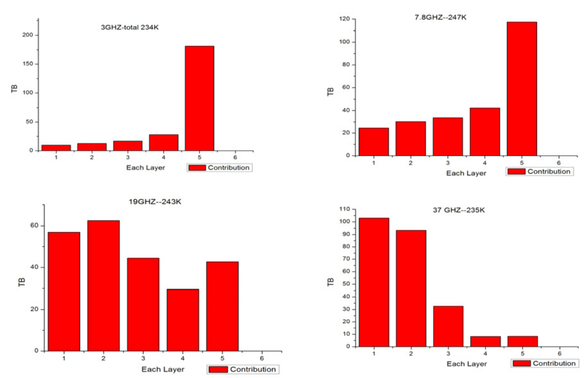

Figure 3: (when S=25) Each layer's temperature's weight (contribution) in the MRM TB measurements.

Finally, we use an S distribution derived from M3 surface measurements [3] and apply the model to retrieve variations in subsurface temperature. The 1m depth temperature map from 0 to ±14N, lunar nearside, is shown in Figure 4, with a topographic map,

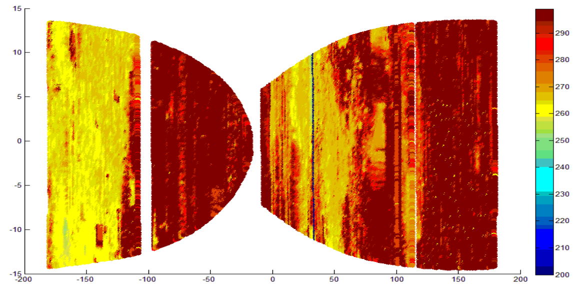

Figure 4: Subsurface temperature at 1m depth.

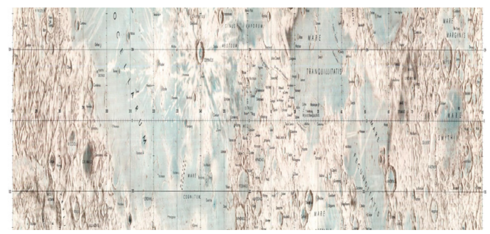

Figure 5. Corresponding area's shaded relief map [4].

From Figure 4 and 5 we may notice that, different geological structures do have different subsurface temperatures, but not simply a difference between maria and highlands. There are two kinds of maria regions. KREEP terrene including Procellarum has a higher subsurface temperature, while the other regions like Crisium and Tranquillitatis etc show lower temperatures. Both of them have similar topography and mineral distribution (iron and titinium)[3]. 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].

4. Conclusion

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.

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 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