Mapping the Moon with Chang'E-1 microwave brightness temperature data

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1 Introduction

During the life time of Chang'E-1 (CE-1), it has covered the entire surface of the Moon many times in a precessing polar orbit 200 km above the lunar surface, transmiting 175 gigabytes(GB) of data to Earth. In this report, we will describe the initial result from our effort analysing the data obtained with CE-1's Lunar Microwave Radiometer (MRM).

Ground-based microwave brightness temperature (TB) distribution map of the nearside of the Moon had been obtained in pre-Apollo times[1]. More recently, lunar brightness temperature data was derived from images acquired by the Clementine Long Wavelength Infrared (LWIR) camera by Lawson et al[2]. Recent lunar orbiters, KAGUYA (Japan) and Chandrayaan-1 (India), have obtained active radar images of the Moon. However, Chang'E-1 brightness temperature data is recognized as the first set of data obtained from passive microwave sensor on lunar orbit that covered the entire Moon in unprecedented resolution. Our results presented here show that CE-1 brightness temperature data can be used to map out detail lunar topography. In addition, the TB maps we produced reveal interesting features not shown in normal UV/Vis maps.

2 Methodology of data analysis

The MRM is one of the scientific payloads onboard CE-1 operating in 4 microwave frequency channels: 3, 7.8, 19.35 and 37 GHz. Raw data received from MRM are preprocessed by CAS (Chinese Academy of Sciences) to a distributable PDS (Planetary Data System) format. Each record in the set contains orbital information of CE-1 when and where the measurement being made and the measured physicsal quantities. In the final form that is employed in this analysis, the relevant quantities in each record are: the UTC time of the measurement, brightness temperature from the 4 microwave channels, solar incidence angle, solar azimuth angle, and the orbital information of CE-1 (longitude, latitude and orbital altitude).

Unlike surface temperature on Earth (which depends mostly on the local atmospheric condition), local surface temperature on the Moon depends just on its spatial relationship with respect to the Sun. Hence a crucial step in our analysis is to establish the dependence of TB on the hour angle to model the diurnal variation and the dependence of TB on the lunar latitude, which is traditionally described by the Lambertian model or the model of Pettit and Nicholson[3].

In Figure 1, surface plot of such a model for the highest frequency channel (37 GHz, in the region with -60<latitude<60) is shown. The vertical axis is the brightness temperature in degree K and the horizontal axis stands for the hour angle (with noon at the middle). The wiggle represents the diurnal variation which is maximal near the equator. Similar models can be obtained for the other frequency channels. The root-mean-square deviations of the TB data from the model fits used below are 2.4, 4.0, 3.5, 3.8 respectively for the 4 frequency channels. These deviations, which include the soil and shadow effects, are quite small compared to the full range of temperature variations. They also indicate that the instrumental errors are small.

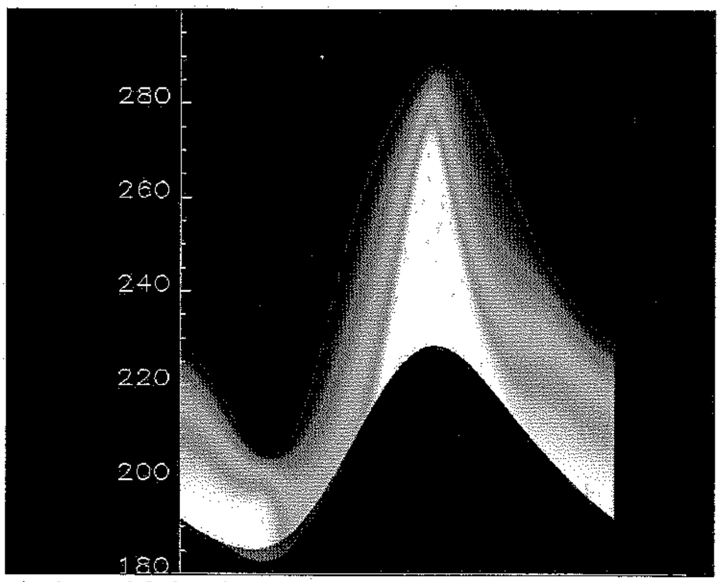

Figure 1: Diurnal variation model for the 37GHz frequency channel. The vertical axis is the brightness temperature in degree K and the horizontal axis stands for the hour angle.

The model of diurnal/latitude variation gives us the ability to map the brightness temperature of different parts of the Moon at the same local time, e. g. at noon or mid-night, by subtracting out the diurnal (and latitude) variation and rescale. This process brings out the variation of TB due only to the local topographic and soil condition and distinguishes this work from previous[4]. So that the map constructed this way may reveal features that depend on local topography and soil physics.

3 Results

Our result can be exemplified in Figures 2 and 3, in which maps of the rescaled TB from the two of the microwave channels (with the longest and shortest wavelengths) are shown. To avoid distortion from the polar regions, we truncated the map with latitudes beyond 60 degrees north and south. These maps show features amazingly close to the visible topographic features shown in the Clementine lunar UV/Vis images. The topographic features are most clearly shown in Figure 3, which represents TB data from microwave channel with the shortest wavelength (0.81cm) and reflects mainly the surface condition. In general, TB of the lunar maria is higher than that of the highlands, a fact that was noticed by early researchers[1] as well. Figure 2 is the TB map constructed from the longest wavelength (10cm) data and reveals features not seen in normal images with visible spectrum. These "new" features are likely related to the physical properties of deeper layers in the lunar regolith.

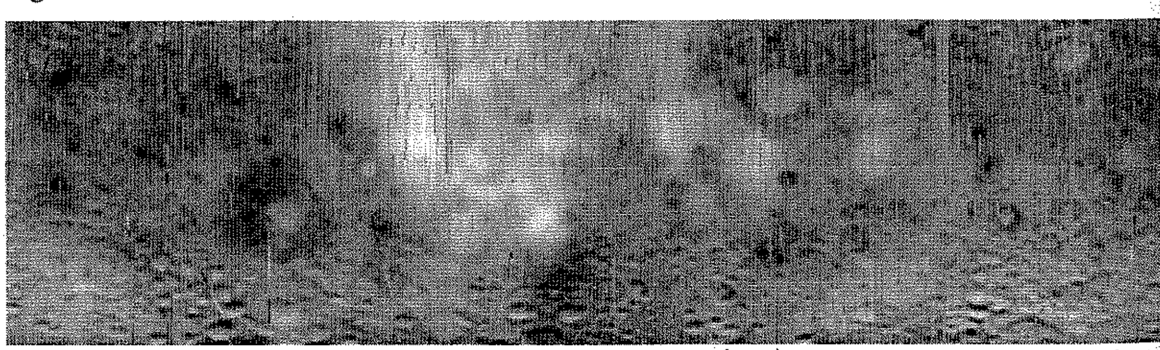

Figure 2: Daytime microwave brightness temperature, 3GHz (10cm) channel, for the region with -60<latitude<60, -180<longitude<180

Figure 3: Daytime microwave brightness temperature, 37GHz (0.81cm) channel, for the region with -60<latitude<60, -180<longitude<180

Another interesting feature we notice is shown in Figure 4, in which we compare the day-time and night-time highest frequency TB map inside a small lunar region with 0<latitude<50, -70<longitude<-10. From visual inspection of the plots placed side by side, it is obvious that there is an anti-correlation existed between the underlying data. Indeed, when a routine statistical calculation is performed we found the correlation coefficient between the two set of data to be -0.6, indicating the existence of a significant anti-correlation. This may be explained as whatever surface material heating up to a higher temperature during day-time also cooling down to a lower temperature at night.

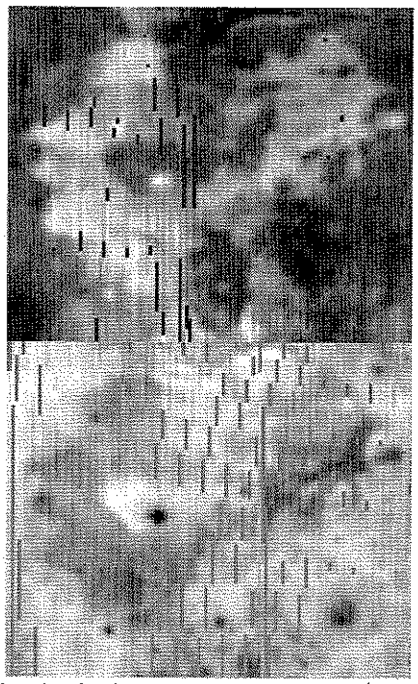

Figure 4: Day-night anti-correlation in the longitude x latitude = (-70, -10) x (0, 50) region (Mare Imbrium, Oceanus Procellarum)

4 Discussions and future plan

With the high spatial resolution CE-1 microwave TB data and the data analysis we have developed in this work, it is likely that we are just at the beginning of revealing deeper secrets of the lunar regolith. This acheivement is unprecedented because no short wavelength (UV/Vis) imaging can see through the surface. We will continue to further study TB mapping technique and the CE-1 microwave TB data so that they may become useful tools for lunar exploration. Using the new information, we can proceed to extract the physical implications that can be derived.

Acknowledgement

We thank the Moon Data Center for technical assistance. This work is supported by the Research Competitive Program, School of Science of HKUST, and the Research Grants Council of Hong Kong.

References

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