A retrieval of lunar surface rock abundance based on Chang'E-2 microwave radiometer measurements

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Introduction: China's Chang'E-2(CE-2) satellite was launched in 2010, as a duplicate of Chang'E-1, it has obtained the global microwave (MW) thermal characteristics of the lunar surface with a higher space resolution, by a four channel microwave radiometer (37.0GHz, 19.35GHz, 7.8GHz and 3.0GHz)[1]. It is shown that some abnormal "cold spots" can be found from the microwave night observations, which were believed to be closely related to rock existence on the lunar surface[2]. Thus, we propose a method to retrieve the rock abundance of lunar surface from the CE-2 37.0GHz observations at night. First, a new temperature profiles of the lunar surface depending on time and depth are discussed using the one-dimensional thermal model, which takes the topography and Adobe factors into account[3]. Then the microwave brightness temperatures (Tbs) both of regolith and rocks are simulated based on the microwave radiative transfer theory. As the measurements are the mixed results by regolith and rock, a weighted average formula is employed to calculate the total microwave thermal contribution, from which the rock fraction could be determined by comparing the simulations with the measurements.

Temperatures: A one-dimensional thermal model with lunar surface topography and albedo is employed to achieve the temperature profiles depending on time and depth[3]:

$$pC\frac{\partial T}{\partial z} = \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) \quad (1)$$

And the boundary conditions are:

$$K(z,T)\frac{\partial T}{\partial z}\bigg|_{z=0} = TSI(1-A)\cos^{+}\theta_i - e\sigma T_s^4 - J_0 \quad (2)$$

$$K(z,T)\frac{\partial T}{\partial z}\bigg|_{z=0} = -J_0 \quad (3)$$

Where TSI is 1414W/m^2, J_0 is 0, and $cos^{+}\theta_i$ is $\cos\theta_i$ if $\cos\theta_i > 0$, otherwise it is 0. And the thermal parameters are adopted same as the former studies.For $\cos\theta_i$, it can be obtained from[3]:

$$\cos\theta_i = \hat{n}_l \times \hat{s} \quad (4)$$

The global surface temperatures for only regolith at midnight (0:00) and temperature profile solved from the one-dimensional thermal model is provided in Fig.1, and the measurements from LRO Diviner T_8 data at a similar time are also presented in Fig.2. It can be seen that the simulation and measurements show a good agreement except that some "hot spots" exist in the observations, which are believed to be closely related to the rocks [2]. By analyzing influence of the difference in Tb simulation next, it is possible to derive the rock abundance of the lunar surface.

For the temperature of pure rocks, the one-dimensional thermal model is employed as well, with the rocks regarded as a semi-infinite space, and the method is following the studies by Bandfield et.al[4]. The results of the temperature variation depending on local time for rocks and regolith are both presented in Fig.3. And for Tycho Crater (43.4°S, 11.1W), a rock abundance of 10% is assumed to validate the temperatures simulated and the influence of rocks.

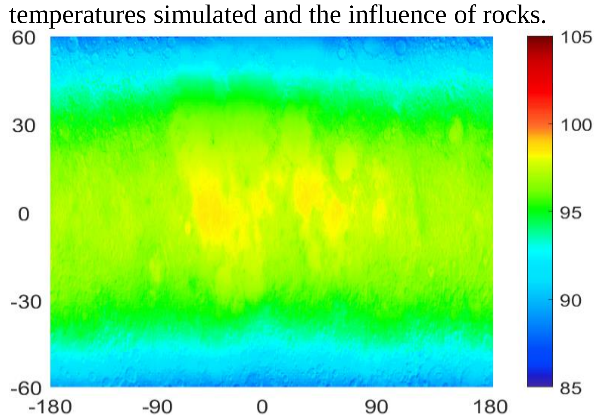


Fig.1 (a) Temperature simulations from one-dimensional thermal model at midnight (0:00)

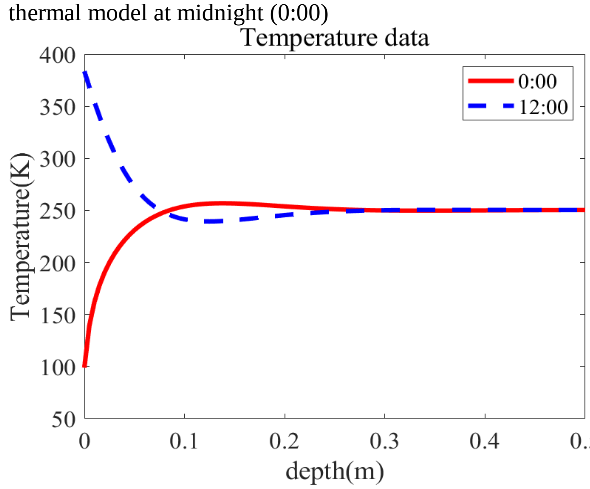


Fig.1 (b) Temperature profile varying with depth for regolith at midnight and noon at the equator

Microwave data: The observations at night (19:30-5:30) between ±60° latitudes from CE-2 microwave radiometer 37.0GHz channel are collected by every hour, and mapping by a 0.5×0.5 degree grid. The midnight observations are shown by Fig.4. It can be found that some "cold spots" distribute in microwave thermal measurements, which might be caused by the existence of rocks. [2]

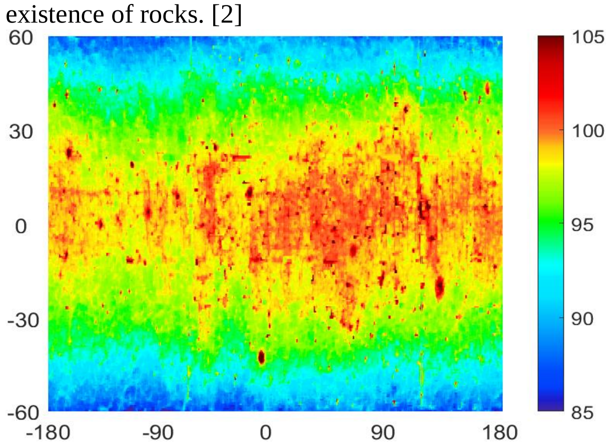


Fig.2 Infrared measurements from Diviner Channel 8 at midnight (23:00-1:00)

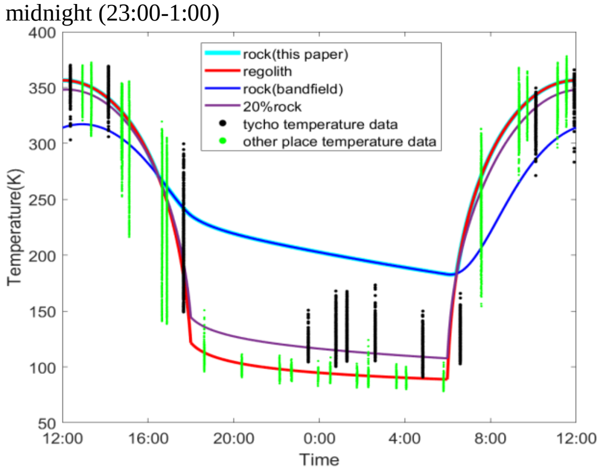


Fig. 3 Surface temperature of rocks and regolith depending on lunar local time and the measurements for validation

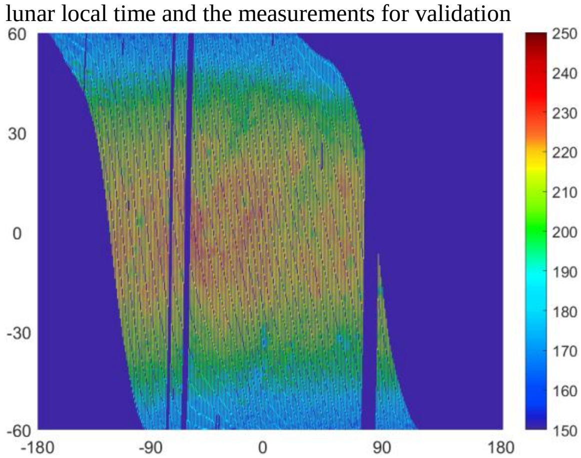


Fig. 4 MW observations from CE-2 at midnight (23:30-0:30)

Microwave Model: If the lunar regolith is taken as isotropic uniform-layered medium, based on the fluctuation dissipation theory and the WKB method, its MW Tb can be obtained by the equation[3]:

$$T_B(0) = [1 - R(0)]\int_0^\infty \kappa_a(z) T(z) e^{-\int_0^z \kappa_a(z')dz'} dz \quad (5)$$

where the loss tangent of the regolith is taken as[3,5]:

$$tan\delta = 3.516\times10^{-4}TiO_2 + 0.0057 \quad (TiO_2>1\%) \quad (6)$$

$$tan\delta = -8.945\times10^{-5}TiO_2 + 0.088 \quad (TiO_2<1\%) \quad (7)$$

Using the temperatures obtained above, the MW Tbs can be simulated at the corresponding time and position.

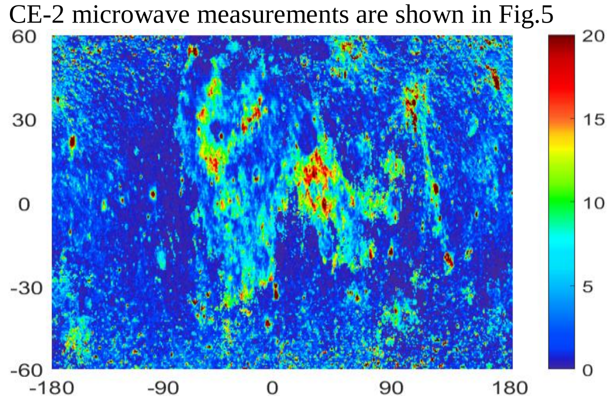
For the simulation of MW Tb of rocks, the same method is adopted, with a dielectric constant ε=8+0.5i [6].

Then a weighted formula:

$$Tb = f_{rock}\, Tb_{rock} + (1-f_{rock})\, Tb_{regolith} \quad (8)$$

is adopted and the rock abundance can be determined from the microwave Tb measurements.

Results: For each CE-2 microwave Tb data collected, the simulation Tbs of rocks and regolith are calculated at the corresponding time and position, and the rock abundance can be calculated from equation(8). The results will be averaged if there are duplicate data at a same place. The global rock abundance derived from the CE-2 microwave measurements are shown in Fig.5



Summary: We use the CE-2 37.0GHz channel microwave measurements to calculate the global rock abundance, utilizing the temperatures solved from one-dimensional thermal model with topography and Adobe. Our results show a good agreement in variation tendency with the former studies by Bandfield[4]. And our rock abundance values is higher, which might be resulted from the better penetration ability of microwaves.

References:

[1] X.Gong et.al (2013) Acta Astronautica 86:237-246 [2]R.W. Shorthill et.al(1965) Science , 150 , 210-212 [3] N. Liu et.al(2020) TGRS, 58,1892-1903 [4] J. L. Bandfield et al.(2011) JGR, 116(E12) [5]X.Gong et.al(2015) GRSL, 12(2):384-388. [6] W.Fa et. Al (2007)JGR,112(E5)