PRELIMINARY ANALYSIS OF MIRCOWAVE BRIGHTNESS TEMPERATURE OF THE LUANR SURFACE FROM CHANG-E 1 MULTI-CHANNEL RADIOMETER OBSERVATION AND INVERSION OF REGOLITH LAYER THICKNESS. Ya-Qiu Jin[1], Wenzhe Fa[1,2] and Mark A. Wieczorek[2], [1]Key Laboratory of Wave Scattering and Remote Sensing Information (MOE), Fudan University, Shanghai 200433, China (yqjin@fudan.ac.cn), [2]Institut de Physique du Globe de Paris, France (wzfa@ipgp.fr).

Introduction: Previous investigations have shown that, with few exceptions, the lunar surface consists of a regolith layer that completely covers the underlying bedrock. The average thickness of this regolith layer has been estimated to be about 4-5 m for the mare and about 10-15 m for the highlands [1]. Knowledge of the structure, composition and distribution of the lunar regolith provides important information concerning both lunar geology and potential resources for future lunar exploration.

China successfully launched its first lunar exploration satellite Chang-E 1 (CE-1) on October 24, 2007. A multi-channel microwave radiometer was, for the first time in lunar exploration, used for the purpose of measuring the microwave thermal emission from the lunar surface [2]. In this study, lunar day and nighttime microwave brightness temperature maps are constructed using the CE-1 observations from November 2007 to February 2008. Based on a three-layer model of the lunar near-surface regolith layer, the brightness temperature measurements and their dependence on latitude, frequency and $FeO+TiO_2$ content have been investigated. Using an empirical model of physical temperature with latitude, a global regolith thickness map has been inverted using the low frequency brightness temperature measurements. Based on our global regoith thickness results, we estimate the global abundance of ^3He in the lunar regolith.

Lunar Brightness Temperature from Chang-E 1: There are four frequency channels on the CE-1 microwave radiometer: 3.0, 7.8, 19.35 and 37.0 GHz. The observations are nadir looking, the spatial resolution is about 30 to 50 km on the surface, and the radiometric sensitivity is about 0.5 K. Brightness temperature measurements for each orbit are highly dependent upon the observation time and surface latitude. On the basis of the observed relation between brightness temperature and solar incidence angle, 264 orbital tracks with solar incidence angles of 0-14° and 166-180° at the lunar equator were selected to construct global brightness temperature maps near lunar noon and midnight, respectively. As an example, Figure 1 shows the obtained brightness temperature map from the 37 GHz channel near lunar noon.

In the global brightness temperature maps of the lunar surface, temperatures are high at equatorial latitudes and decrease towards the poles. This trend is a direct consequence of the latitudinal dependence on the physical temperature of the surface. A significant difference in brightness temperature is observed between the daytime and nighttime observations that is a direct reflection of the extreme variations in physical temperature over a lunation.

In comparing the daytime brightness temperature maps with combined $FeO+TiO_2$ abundances [5], it is clear that the two are highly correlated for the observations at 7.8, 19.35 and 37 GHz. The mare, with high $FeO+TiO_2$ abundances, have high brightness temperatures, whereas the highlands, with low $FeO+TiO_2$ abundances, have lower brightness temperatures. Nevertheless, the brightness temperatures of the mare and highlands for the nighttime observations are almost indistinguishable. All of these observations are consistent with our three-layer theoretical model that described below.

Three-Layer Model for Microwave Emission: Brightness temperatures of the lunar surface correlate principally with the physical properties of the regolith layer, such as the regolith thickness, physical temperature, and dielectric permittivity. Based on our current knowledge of the physical temperature and bulk density of the near-surface regolith layer [3,4], a three-layer model consisting of an upper dust layer, a regolith layer, and an underlying bedrock is used for simulating the microwave brightness temperature. A physical temperature profile is first specified [3], and the radiative transfer equation for stratified media is then used to calculate the predicted brightness temperature.

The upper dust layer of the Moon is highly insulating in comparison to the underlying regolith, and as a result of this, its temperature is strongly dependent on the solar insolation and local time of day. In contrast, the temperature variations experienced by the underlying regolith layer and bedrock are considerably more subdued. For our initial simulations, we assume that the physical temperature is constant (though different) in each of the three layers. Future modeling will employ a more realistic temperature profile.

Simulation results show that the brightness temperature increases as the regolith thickness increases, approaching an asymptotic value at large thicknesses. During the lunar daytime, the high-frequency channel is predicted to have the highest brightness temperatures since most of the energy is radiated by the upper dust layer. In contrast, during the lunar nighttime the low frequency channel (with a much larger prenetation depth) has the highest brightness temperature because the highest temperatures are located below the surface.

Inversion for Regolith Layer Thickness: Since the microwave penetration depths for the 19.35 and 37 GHz channels are very small, they are insensitive to regolith layer thickness. When the physical temperature and the dielectric constant of each layer in our model is known *a priori*, the 3 GHz channel observations, which possess the largest penetration depth, can thus be used to invert for the regolith layer thickness.

The global distribution of dielectric constant is estimated using an empirical relationship between bulk density and $FeO+TiO_2$ abundance [3,4], with the $FeO+TiO_2$ abundances being taken from the Lunar Prospector γ-ray spectrometer [6]. For our initial inversion of regolith thickness, we have used a constant (though different) temperature for each of the layers in our model. Using seismically obtained regolith thicknesses at the Apollo landing sites as a model input, the dust layer thickness is first estimated to be 0.13 m thick. Next, we use a dependence of physical temperature on latitude for the lunar dust layer that is taken from an analysis of the Clementine infrared data [7] and a temperature dependence for the regolith layer that is taken from [3]. These physical temperature models are consistent with the physical temperatures obtained from the high frequency channels of the Chang-E 1 radiometer.

Figure 2 shows our inversion results for the thickness of the regolith layer using the 3 GHz noontime data. The low regolith thicknesses on the lunar nearside correspond to the mare, whereas the higher values correspond to the highlands. The systematic difference of regolith thickness between the mare and highlands is a natural consequence of the difference in age of the surfaces. The low regolith thicknesses obtained near the poles are likely to be an artifact of our physical temperature model of the lunar surface, though it is possible that the lower predicted impact fluxes at the poles [8] could contribute to this signal as well.

The lunar mare are characterized by reoglith thicknesses that vary from 1.2 to 11 m. Our results show that the thinnest regolith thicknesses occur in Mare Imbrium, and that the thickest regolith occurs in Mare Fecunditatis and Mare Nectaris. The thickness of the highlands regolith varies from 1.0 to 15 m, and for the lunar farside, the regolith layer thickness is in general greater than 8 m at equatorial latitudes. The average regolith thickness of the mare is 4.5 m, and that for the equatorial highlands (<60° latitude) is 7.6 m.

Global Inventory of Helium-3 in Lunar Regolith: ^{3}He in the lunar regolith, which is implanted by the solar wind, is one possible valuable resource because of its potential as a fusion fuel. The abundance of ^{3}He in the lunar regolith is related to the solar wind flux, lunar surface maturity and TiO_2 content [9]. Based on Apollo regolith samples, a linear relation between ^{3}He abundance and normalized solar wind flux, optical maturity and TiO_2 content is here used to estimate the distribution and global abundace of ^{3}He [10]. Using our global regolith layer thickness estimates from the CE-1 radiometer, the total amount of ^{3}He per unit area in lunar regolith layer is obtained. The global inventory of ^{3}He is here estimated to be 6.58×10^8 kg, with 3.72×10^8 kg coming from lunar nearside and 2.86×10^8 kg from the lunar farside.

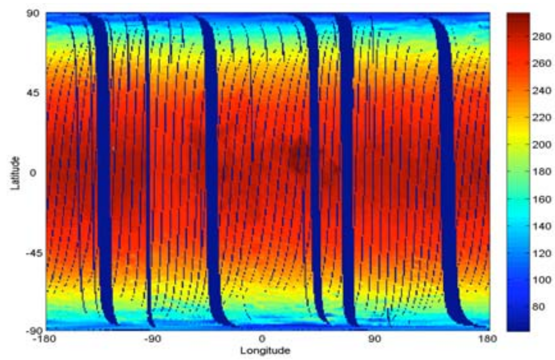

Figure 1. 37 GHz brightness temperature (K) of the lunar surface at noon (solar incidence angles between 0 and 14°). The dark blue stripes do not contain data.

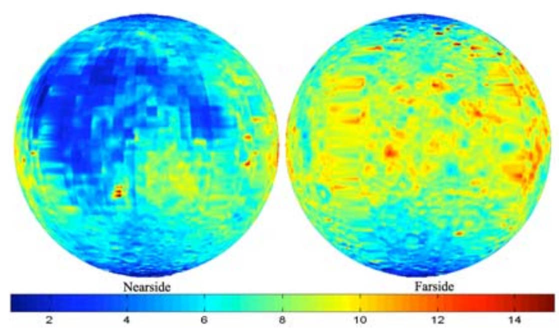

Figure 2. Global distribution of lunar regolith layer thickness (in meters) inverted from Chang-E 1 daytime microwave radiometer data.

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