MILLIMETER LUNAR MICROWAVE RADIANCE: MODEL SIMULATION AND SATELLITE OBSERVATIONS

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ABSTRACT

As a potential external calibration reference for spaceborne microwave sounding instruments, accurate and reliable information of lunar disk-averaged radiance at millimeter band are important and fundamental. Based on study for 2-D lunar scans of the Advanced Technology Microwave Sounder(ATMS) on board the NOAA-20 satellite, the lunar radiance spectrum from 23 to 183 GHz at full moon phase has been reported in our previous work. In this study, based on radiative transfer model simulations, lunar microwave radiation at millimeter band was computed and compared with the ATMS observations. Significant improvement in the accuracy of the moon as a calibration standard at mm wavelengths could be made by using highly accurate satellite observations to reduce the uncertainties in the lunar electrical property model.

Index Terms— Radiative transfer model, millimeter lunar brightness temperature

1. INTRODUCTION

Lunar surface reflectance and emissivity properties are extremely stable, and can be known to high precision. Several recent papers have discussed the potential of using the Moon as an international standard traceable calibration target for spaceborne microwave sounding radiometers [1–3]. For lunar calibration of microwave sounding instruments, accurate knowledge for the variation of lunar brightness temperature (Tb) with Moon phase angle over a wide range of detection frequencies are fundamental. In recent years, with the observations obtained from the Diviner Lunar Radiometer Experiment instrument (DLRE) onboard the Lunar Reconnaissance Orbiter, improvements have been made to the thermal model for lunar surface and subsurface temperatures simulations[4]. The lunar thermal temperature profile can now be simulated with a high accuracy when compare with ground truth[5]. Microwave radiation can penetrate to lunar sub-surface; thus the microwave thermal emission in terms of brightness temperature can be quite different from surface temperature. Efforts have been made to simulate the lunar microwave radiation since 1960s[6–9]. Although some improvements have been made in recent years based on lunar orbit optical and microwave satellite observations[10–11], There are still some difficulties for accurate lunar microwave emission model development in millimeter band. One of the major challenges is the uncertainty in the lunar regolith electrical absorption properties. Recently we reported the lunar disk averaged radiance spectrum from 23 to 183 GHz for full moon phase based on analysis of 2-D lunar scans of the Advanced Technology Microwave Sounder(ATMS) on board the NOAA-20 satellite[12]. The overall goal of this study is to compare simulated lunar Tb at millimieter band with satellite observations. The Radiative Transfer Model developed by Keihm was used for this purpose [9], with input thermal profiles generated from a 1-D heat conduction model developed by Hayne et al.[5]. In this paper, section(2) introduces the lunar microwave RTM model. Lunar tb simulation results are presented in section (3). Section(4) describes comparison results between model and satellite observations. Summary and conclusion are included in section(5).

2. RADIATIVE TRANSFER MODEL

Microwave brightness temperature of lunar emission can be calculated as convolution of microwave electrical loss with lunar regolith temperature profile over different depth[11]:

$$TB(\lambda) = E_\lambda \int_0^\infty K_\lambda \sec(\theta_i) \cdot T(z) \cdot e^{-\int_0^z K_\lambda(z') \sec(\theta_i)} dz \tag{1}$$

The discrete form can be written as weighting sum of thermal temperature at each layer:

$$TB(\lambda) = E_\lambda \sum_{i=1}^{i=n} w_i * T_i \tag{2}$$

with weighting coefficient $w_i = K_\lambda^i \cdot e^{-\int_0^z K_\lambda(z) \sec(\theta_i) dz}$ In equation above, K_λ is the wavelength-, depth- and temperature dependent microwave absorption, $T(z)$ is the physical

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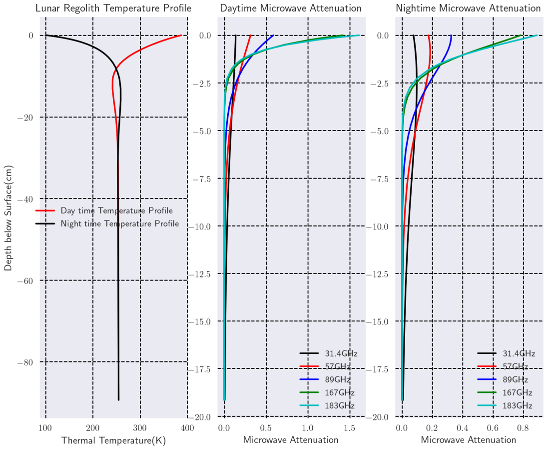

Fig. 1. The daytime and nightime lunar regolith temperature profiles and microwave attenuation profiles at seltected ATMS frequencies

temperature profile, E_λ is the surface emissivity, and TB_λ is the observable brightness temperature. θ_i are emergence angle. $\epsilon^{'}$ is the real part of the dielectric constant of lunar regolith. The details of calculation for these model parameters can be found in [9]. Figure.1 shows the input temperature profile for local noon and mid night at the center of lunar front disk. Also presented are the corresponding microwave electric loss weights at different frequencies. It is seen that while the higher frequency is much more sensitive to the microwave emission at the near-surface layers above 2.5cm, the emission from deeper layer have more contribution for the top of surface(TOS) Tb of lower frequency bands, most notably for the night time microwave radiation when there is no incident solar flux.

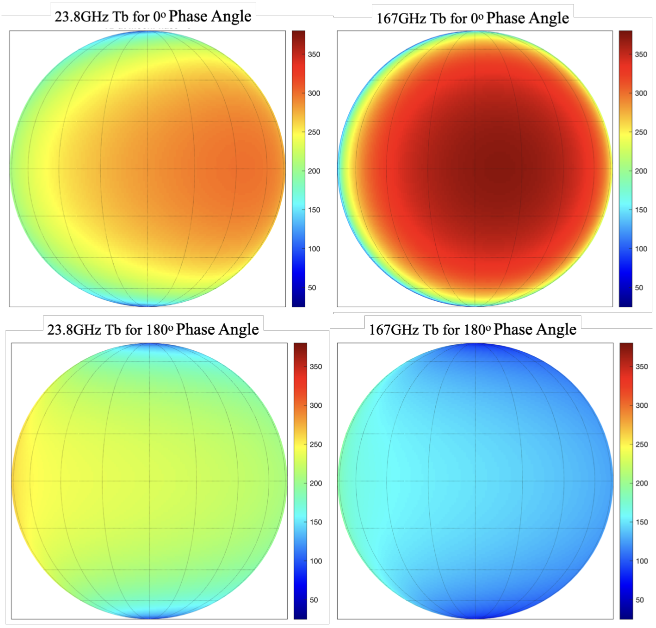

Fig. 2. The simulated front side lunar disk Tb of full Moon(local noon) and new moon (local mid night) for 23.8 and 183GHz

3. LUNAR DISK MICROWAVE BRIGHTNESS TEMPERATURE SIMULATIONS

As discussed before, currently there is no practical model to calculate the effective surface emissivity at millimeter band. Almost all previous analysis of lunar microwave emission have assumed a locally plane-parallel surface and a Fresnel emissivity. Realistic departure from this asumption, both large-scale and small scale roughness can contribute to brightness temperature changes[9]. For this work, the emissivity in Eq(2) was set to 1 in the simulation, so that only the ”black body” emission will be simulated. While this approach will overestimate the effective lunar Tb, it can also reduce the uncertainty in the simulation when Fresnel reflection function is used. Figure.2 shows the simulated lunar disk front side microwave Tb color maps for 23.8GHz(12.6mm) and 167GHz(1.8mm). Both simulations at full moon(0°) and new moon(180°phase angle) are presented with resolution of 1°by 1°for comparison purpose. It is seen that while the distribution of microwave Tb on lunar disk is impacted by latitude and local phase angle, there is significant asymmetry in the Tb distribution at low frequency. Also noticed is that compare to higher frequency, the Tb in low frequency is colder in full moon and warmer in new moon. The disk-averaged Tb can then be calculated as weighting sum of global Tb as below:

$$Tb^{Disk}(\lambda) = \sum_{\phi=-90}^{\phi=90} \sum_{\theta=-90}^{\theta=90} Tb_i(\theta,\phi) w_i(\theta,\phi) \qquad (3)$$

where the weights $w_i(\theta,\phi) = \frac{\cos\theta\cos\phi d\theta\ d\phi}{\sum w_i(\theta,\phi)}$. The dynamic Tb variation with phase angle and the asymmetry can be clearly seen in disk-averaged Tb, as shown in figure.3. The asymmetry can be explained by the larger phase lag in the longer wavelength due to the penetration depths characteristic of microwave radiation[6][9].The phase lag angle decreases from 36°in 23.8GHz(12.6mm), 16°in 89GHz to 9°in 183GHz(1.6mm), which are close with those derived from satellite observations in our previous study [13].

4. COMPARISON BETWEEN MODEL SIMULATION AND SATELLITE OBSERVATIONS

In our previous study, the disk-integrated lunar Tb spectrum from 23 to 183 GHz of full-Moon was derived based on 2D lunar scan observations from the ATMS instrument onboard

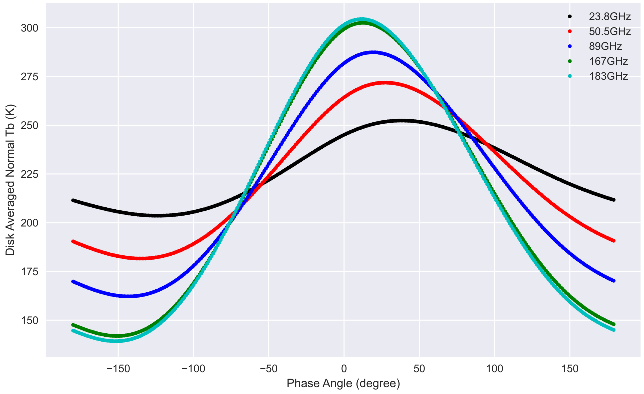

Fig. 3. The simulated lunar disk averaged black body Tb variation with Moon phase angle for frequency from 23.8 to 183GHz

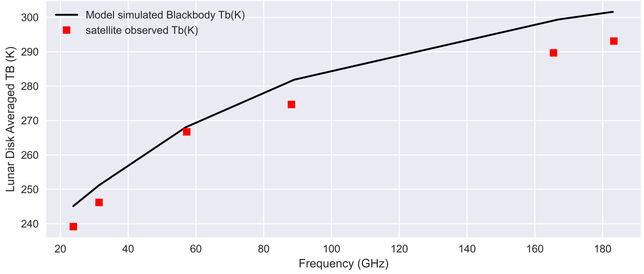

Fig. 4. The disk-integrated lunar brightness temperature spectrum and effective emissivity at full-Moon phase

the NOAA-20 satellite. This data set provides a unique opportunity to compare with the model simulations and assess the accuracy of the lunar RTM model. As shown in Figure 4, the trend of lunar simulated disk average Tb spectrum of full moon shows great consistency with satellite observations. The magnitude of simulated Tb is systematically warmer than satellite observations, which is reasonable considering the fact that the current model is only for ”Black body” microwave emission of lunar surface and therefore will overestimate the effective lunar Tb. It also should be noted that while the satellite observation is mix-polarized, which is Quasi-V for 23,31 and 89GHz, and Quasi-H polarization for 50,167 and 183 GHz, the closely matched spectrum trend between the ”black body” simulations and satellite observations indicate that the lunar disk-average Tb at the millimeter band under investigation might be unpolarized. It is also observed that the ratio between satellite observation and simulations decrease with increased frequency, which might be caused by a frequency dependent feature of lunar surface microwave electrical properties.

5. SUMMARY AND CONCLUSIONS

Most of current operational microwave sounding instruments onboard weather satellites are operated in millimeter wavelength. Presented in this study is a comparison of simulated disk-integrated lunar Tb with satellite observations. It is observed that there are consistent phase lag and frequency dependent Tb trend between model simulation and satellite observations. In this study, only multi-layer microwave emission caused by electric loss was taken into account in RTM model, and the emissivity of lunar regolith surface was set to 1. While this approach will overestimate the effective lunar Tb, it can also reduce the uncertainty in the simulation when simple surface emissivity model such as Fresnel reflection function is adopted. Since peak lunar TB values and phase lags at mm wavelengths are particularly sensitive to the absorption and scattering losses in the regolith porous surface layer, a significant improvement in the accuracy of the moon as a calibration standard at mm wavelengths could be made by using satellite observations. In this work, comparison is only delivered for the full-Moon case. Satellite observations collected at different lunar phase angle will be included in future work.

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