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Determination of the dielectric constant of the lunar surface based on the radar echo intensity observed by the Kaguya

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In the planetary radar observation, echo power and delay time depend on the effective dielectric constant, or equivalent dielectric constant including the voids in the planetary uppermost media. As for the Moon, because there is almost no material whose dielectric constant is far from the basalt rocks, the effective dielectric constant of the lunar uppermost media is considered to depend mainly on their porosity. So if we can determine the effective dielectric constant of the lunar uppermost media, we can derive their bulk density, or density including the voids based on the empirical relation between the dielectric constant and bulk density of the Apollo samples [Carrier et al., 1991].

If we are going to use echo power for determination of the permittivity, we should note that the radar echo intensity depends not only on the dielectric constant but also on the roughness of the surface. Therefore, we have determined the permittivity of the lunar surface with considering the surface roughness. In the analysis, the dielectric constant is determined by using the radar echo intensity obtained by Kaguya Lunar Radar Sounder (LRS) [Ono et al, 2000; 2008; 2010], and the surface roughness parameters derived from Digital Terrain Model (DTM) based on Kaguya Terrain Camera (TC) observation [Haruyama et al., 2008]. The global distributions of the echo powers in a frequency range of 4-6 MHz were derived from the Kaguya/LRS dataset. We have used the intensity of off-nadir echoes in an incident angle from 5 to 15 degree. The reason why nadir echoes are not used in the analysis is because the echo intensity changes drastically in small incident angle range due to the poor range resolution from the spacecraft to the off-nadir reflection point. The echoes arrived after the arrival of the nadir surface echo were identified as off-nadir echoes in this study. In addition, we have also derived the global distribution of the surface roughness parameters. The RMS height of the surface can be obtained by $<$(z(x+L)-z(x))^2$>$, where z(x) is height of the surface derived from the Kaguya TC/DTM, L is baseline length, and $<>$denotes the average. If we assume the self-affine surface model, the roughness parameters H and s can be obtained by the least square fitting of the RMS heights to s L^H. The off-nadir surface echo power can be calculated based on the radar equation. Assuming Kirchhoff Approximation (KA), the backscattering coefficient in the radar equation can be obtained from the roughness parameters H and s, and assumed dielectric constant [cf. Bruzzone et al., 2011]. Using the backscattering coefficient, we can calculate the expected off-nadir surface echo powers. By performing the comparison between calculated and observed echo powers, we can determine most plausible dielectric constant. In the calculation of the echo powers, the transmitting loss of LRS have to be determined, which are however difficult to measure in the ground tests. So we estimated the transmitting loss to be 5.8 dB by assuming that the average dielectric constant is to be 5.3, which are derived from bulk density of 2.55 g/cm3 in the highlands reported based on GRAIL observations[Wieczorek et al., 2013].

The obtained Hurst exponent H is less than 0.5 in the maria, and about 0.9 in the highland. The parameter s is about 1 in the maria, and about 0.3 in the highland. By applying the analysis method mentioned above, we could obtain the observed and calculated surface echo powers in the regions where H˜0.5, and H˜0.9. Based on them, we could estimate the average dielectric constant in the maria (H?0.5) to be 7, and that in the highland (H?0.9) to be 4. The bulk densities are therefore estimated to be 3.0g/cm3 in the maria (H˜5), and 2.1g/cm3 in the highland. It suggests that there are more voids in the highland than in the maria due to longer exposure to the meteorite impacts.

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Terrain Camera (TC), Surface roughness, Bulk density, Dielectric constant