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Constraints on the density and porosity of the lunar highlands crust from gravity and topography

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Abstract

A localized spectral analysis of gravity and topography has been applied to the lunar highlands. Assuming that surface and subsurface loads are elastically supported by the lithosphere, the density of the lunar farside highland crust has been constrained at a number of locations, yielding values between about 2850±100 to 2950±100 kg/m^3 with elastic thickness constrained to be larger than 10 km. When combined with independent knowledge of crustal density based on compositional data obtained from remote sensing data, the porosity of the upper few kilometers of the crust is estimated to be between 1 and 3%.

1. Introduction

Gravitational and topographic data can provide information on the structure and rheology of a planet's interior. It is often advantageous to investigate those relationships in the spectral domain from which the linear transfer function ("admittance") can be used to invert for geophysical parameters such as crustal thickness, elastic thickness, crustal density, and the ratio of surface and subsurface loads [1]. The Japanese lunar explorer *Kaguya (SELENE)* obtained the first global gravity model by using 4-way Doppler tracking on the lunar farside, and highly accurate topographic models are now available from several spacecrafts, including *Kaguya (SELENE)*, *Chang'e-1*, and *Lunar Reconnaissance Orbiter*. Using these data, it is now possible to investigate systematically the lunar farside structure.

2. Spectral Analysis

The crustal density and elastic thicknesses are investigated using topography obtained from *Kaguya (SELENE)* (LALT_SH.TAB) and the most recent spherical harmonic model of the global gravity field SGM100h [2]. Owing to the limited 4-way Doppler measurements, the gravity coefficients are only valid globally to degree and order 70. Nevertheless, shorter wavelengths can still be analyzed locally in regions where the gravity coverage is good and the signal is strong. Localized admittance and correlation spectra were calculated by windowing the free-air gravity and surface topography with the band-limited localization windows of Wieczorek and Simons (2005) [3]. The localization windows are constructed to minimize the signal arising exterior to the region of interest for a given spectral bandwidth. We chose a single localized window with bandwidth L such that 99% of its power was concentrated in the region of interest. In order to neglect rotational and tidal contributions, localized admittances were analyzed between the degrees L+3 and L_{data}-L, where L_{data}=100 corresponds to the maximum degree of the SGM100h gravity model.

3. Admittance/Correlation Results

We first considered the case where the lithosphere is treated as a thin elastic spherical shell and on which only surface loads are present. In this top-loading model, the amount of material added to the surface is equal to the final equilibrium topography minus the deflection of the crust-mantle interface [4]. Theoretical gravity fields were calculated as a function of crustal density ρ_c , crustal thickness Tc , and elastic thickness Te . In the model, Young's modulus E is 10^{11} Pa, Poisson's ratio v is 0.25, and the mantle density is 3360 kg/m^3. The crustal density ρ_c was chosen to vary between 2500-3300 kg/m^3, the elastic thickness Te varied from 0 km to 60 km, and Tc was set to the average thickness obtained from the crustal thickness model of [5]. Analyses were mainly concentrated on the lunar highlands that comprise the feldspathic highlands of Jolliff et al. [6]. Figure 1 shows the gravity and topography of two representative localized analyses on both the near and farside hemispheres. The localization window was chosen to have an angular radius 12° and a corresponding bandwidth of L equal to 21. Figures 2 and 3 show the observed localized and modeled admittances and correlations for these two regions, respectively. Our surface-loading model predicts the correlation to be nearly unity, and we hence only model those degrees between the grey vertical lines. For the farside analysis, the average crustal thickness was set to 65 km, and we calculated the misfit from degree 30 to 60. The best fit crustal density was found to be 2950±50 kg/m^3, and the elastic thickness was constrained to be greater than 25 km. For the nearside region, the average crustal thickness was set to 50 km. By considering the degrees from 40 to 70, the crustal density was constrained to be 2900±100 kg/m^3, while the elastic thickness was found to be greater than 10 km.

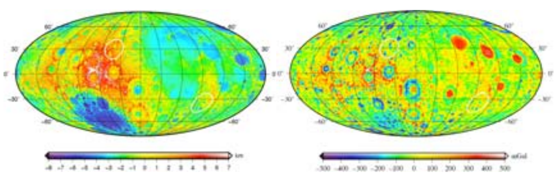

Figure 1. Topography and gravity of the Moon plotted in a Mollweide projection centered on 90°W. The two circles denote the regions analyzed in Figures 2 and 3. The localization window here has an angular radius of 12°.

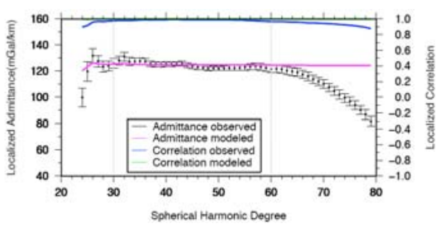

Figure 2. Localized admittance and correlation for the lunar farside highland region (228°, 30°), Black data points and the blue curve represent the observed admittance and correlation, respectively, whereas the magenta and green curves are for the model that best fits the admittance in the degree range denoted by the vertical gray lines.

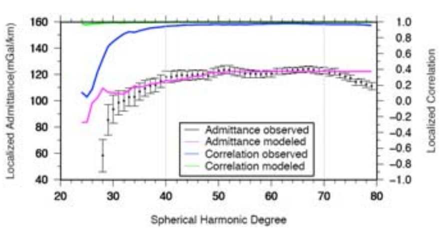

Figure 3. Localized admittance and correlation on lunar nearside highland region (10°, -35°).

4. Summary and Conclusions

By using newly obtained global models of the Moon's topography and gravity field, we applied a localized spectral analysis to several highland regions of the Moon. The localized admittance and correlation functions were then interpreted using a geophysical model that treated the lithosphere is a thin elastic spherical shell. Preliminary results show that the elastic lithosphere supports a surface load, and the crustal density for several regions was found to lie between 2900±100 kg/m^3. By exploiting a correlation between FeO, TiO_2 and density [e.g., 7], we have estimated the "pore-free" density for these regions using independent compositional data obtained from Lunar Prospector [8]. By comparing these two results, the porosity of the upper few kilometers of the lunar crust is estimated to lie between 1 and 3%. We are currently improving upon these results by including both surface and subsurface loads in our inversions.

Acknowledgements

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