Lunar Gravity Studies from the Lunar Prospector Line-of-Sight Acceleration Data

Takayuki Sugano and Kosuke Heki

Department of Astronomical Science, Graduate University for Advanced Studies (Division of Earth Rotation, National Astronomical Observatory)
2-12 Hoshigaoka, Mizusawa, Iwate 023-0861, Japan **E-mail: sugano@miz.nao.ac.jp**

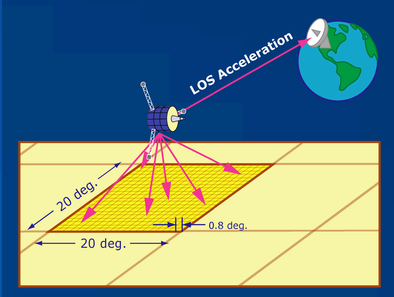
Introduction

Direct estimation of mass distribution on the lunar nearside surface using the Lunar Prospector (LP) line-of-sight (LOS) acceleration data has several merits over conventional methods to estimate Stokes' coefficients of the lunar gravity field, such as (1) high resolution gravity anomaly recovery without introducing Kaula's constraint, (2) fast inversion calculation by stepwise estimation of parameter sets enabled by small correlation between parameters sets.

Resolution of the lunar free-air gravity anomaly map obtained here correspond to as high as a gravity model complete to 225th degree/order, and yet less noisy than the recent 165th gravity model (LP165P) produced by Konopliv et al. (2001).

Next we performed terrain correction for the raw LOS acceleration data using lunar topography model from the Clementine laser altimeter data and the average crustal density of 2.9 g/cm^3. By conducting the same inversion for the data after the correction, we obtained the map of Bouguer gravity anomaly that mainly reflects the MOHO topography.

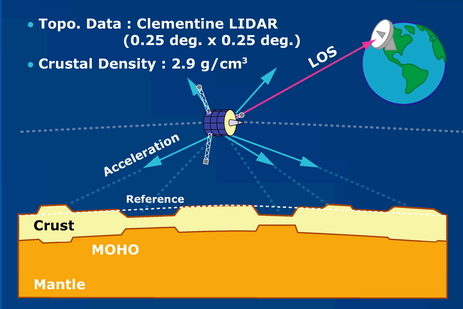
Analysis method of LOS Data



We divide the lunar surface into 20 deg. x 20 deg. "large blocks". They are subdivided into 0.8 deg.x 0.8 deg. "small blocks" (about 25 km x 25 km). The "large block" is the unit for least-square estimation runs, and a "small block" corresponds to a parameter (mass) to be estimated.

The masses in the "small blocks" were estimated using the known geometry between satellite and the blocks. The inversion software was tested using synthesized data set, and the estimated mass distribution was found noisy near the large block rims. So we took out only the central part (10 deg. x 10 deg.) of a large block. These block-wise results are combined to draw the global gravity anomaly map (free-air gravity anomaly map).

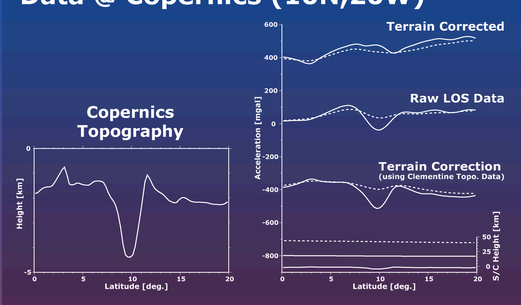
Terrain Correction for LOS Data



Terrain correction was performed for the raw LOS acceleration data using the lunar topography obtained by Clementine laser altimetry and the average lunar crustal density of 2.9 g/cm^3.

The terrain corrected LOS was put into the same inversion software to obtain the map of the Bouguer gravity anomaly, i.e. the anomaly mainly reflecting the MOHO topography.

Data @ Copernics (10N,20W)



Left: The topography of the Copernicus crater from the Clementine laser altimetry.

Right: Three types of the LOS acceleration profiles above Copernicus. The topography is plotted in a scale of spacecraft height. Terrain-corrected LOS acceleration data (top) are obtained by subtracting the acceleration by the lunar topography (bottom) from the raw LOS accelerations (middle).

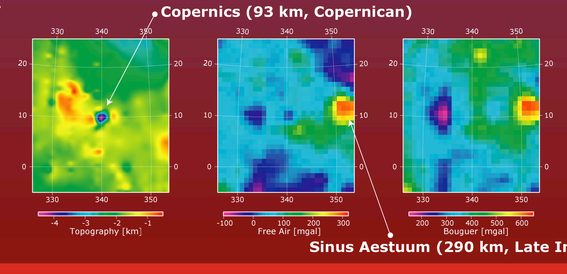
Comparison

	Past works (LP165P etc.)	This work
Software	GEODYN, ODP etc.	homemade
Parameter	harmonic coefficients	surface mass distribution
Computation Time	long	short
Constraint	Kaula's rule	unnecessary*
Region	global	nearside
Degree	165	225

* Our method is applied only for nearside where LOS data is available. On the other hand, the gravity model requires constraint to solve global parameters in spite of no farside data.

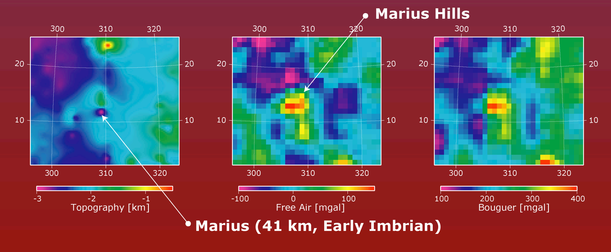
Copernics (10N, 20W)

The Copernics crater, in the Oceanus Procellarum, is one of the youngest craters on the Moon. It is about 4 km deep, and 93 km in diameter. This crater shows weak negative free-air anomaly, but no signatures in the Bouguer anomaly map, i.e. a typical uncompensated crater. The both gravity maps show strong positive anomalies east of Copernics, known as the Sinus Aestuum (290 km in diameter) possibly of volcanic origin. This might be a source conduit of flood basalt that filled the Oceanus Procellarum in the late Imbrian period.



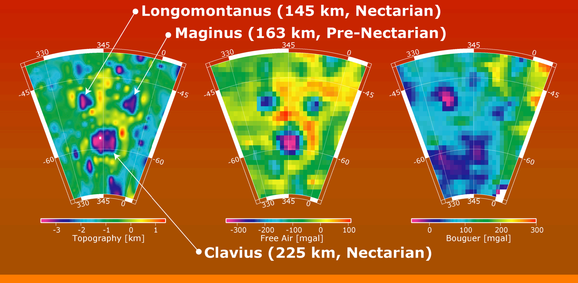
Marius Hills (11.9N, 50.8W)

The Marius crater is in the Oceanus Procellarum. This area shows strong positive signatures in both of the gravity maps. Considering its small size (too small to cause MOHO uplift), it would be of volcanic origin. This interpretation is consistent with topographic features around Marius suggesting relatively recent vigorous volcanic activity such as volcanic domes. This area is known as the Marius Hills.



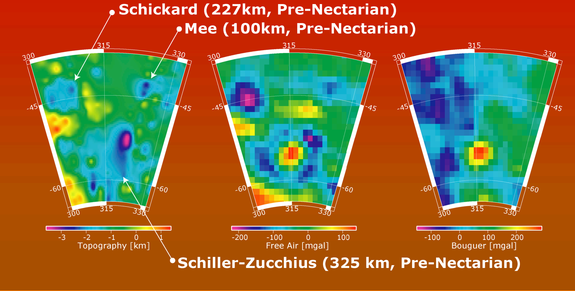
Clavius (58S, 14W)

There is a cluster of three intermediate size craters (Clavius, Maginus and Longomontanus) to the south of Tyco. They show negative free-air signals, and the Bouguer anomalies are also negative (except Maginus), i.e. they are "enhanced" craters. Maginus' deep structure is unclear because it seems to have been affected by a neighbouring positive Bouguer anomaly. This anomaly suggests that there is high density lava in (or bottom of) the crust. The lava couldn't reach the surface because of the thick highland crust.



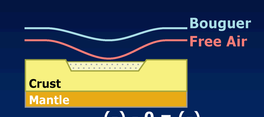
Schiller-Zucchius (56S, 45W)

There are three neighbouring craters (100 km to 325 km in diameter) to the south of Mare Humorum. Schickard and Mee show uncompensated gravity signatures. On the other hand, Schiller-Zucchius gravity anomaly is positive in both of the gravity maps, i.e. it is a "mascon". The transition from uncompensated to mascon craters seems to occur between 230 km and 330 km in diameter.



Gravity Signal above various Craters

after Reindler and Arkani-Hamed [2001]



(-) - 0 = (-)

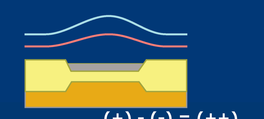
(1) Enhanced Crater
Small old craters were often filled with ejecta from nearby newer craters or avalanche deposits from its own rim. Both free-air and Bouguer gravity anomalies are negative above them, because the filling materials are porous (light) and the MOHO topography is flat.

(-) - (-) = 0

(2) Uncompensated Crater
If the crater is fresh and small enough to be supported by lithospheric strength (i.e. not isostatic compensation), negative free-air anomaly disappear in the Bouguer (terrain-corrected) anomaly map.

0 - (-) = (+)

(3) Compensated Crater
A larger crater is often associated with mantle plug (uplifted MOHO topography) to attain isostatic compensation. Free-air anomaly is very small above such a crater while the Bouguer map show positive anomaly reflecting the MOHO uplift.



(+) - (-) = (++)

(4) Mascon
A compensated crater which were filled with basaltic lava flow after attaining the isostacy, becomes "mascon". Above a mascon, both free-air and Bouguer anomalies show strong positive signals due to both the excess masses of the lava and the mantle plug.

F.A. - Topo. = Bouguer

MOHO topography for various crater size/elastic thickness

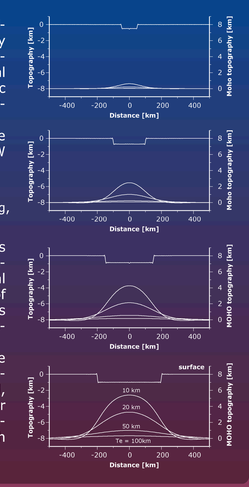
MOHO topography is mainly controlled by two factors (1) flexural rigidity of the lithosphere, and (2) wavelength of the topography. The flexural rigidity D is represented by the elastic thickness of the lithosphere T_e [Forsyth, 1985].

If the surface topography is H, the amplitude of the MOHO topography W is estimated as follows.

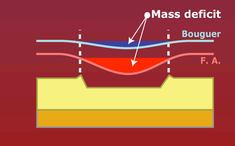
$$W(n) = -\rho H(n)/\Delta\rho\xi(n) \text{ with}$$
$$\xi(n) = 1 + D\nu^2(n+1)^2/R^4\Delta\rho g + EH/R^2\Delta\rho g,$$
$$D = ET_e^3/12(1-\nu^2)$$

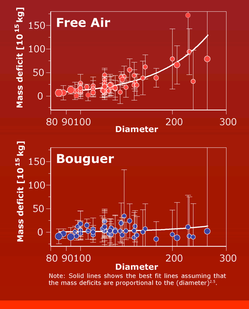
where ρ is the crustal density, $\Delta\rho$ is the density contrast at the crust/mantle boundary, g is the gravitational acceleration, and n is the degree of spherical harmonics. Young's modulus E is taken as 0.4×10^{11} N/m^2 and Poisson's ratio ν as 0.25.

If the crater size is small, then the MOHO topography is low for any lithosphere thickness. On the other hand, the larger the crater size, the higher the MOHO uplift. In addition, the thinner lithosphere thickness causes high MOHO uplift.



Mass deficits associated with intermediate-sized craters

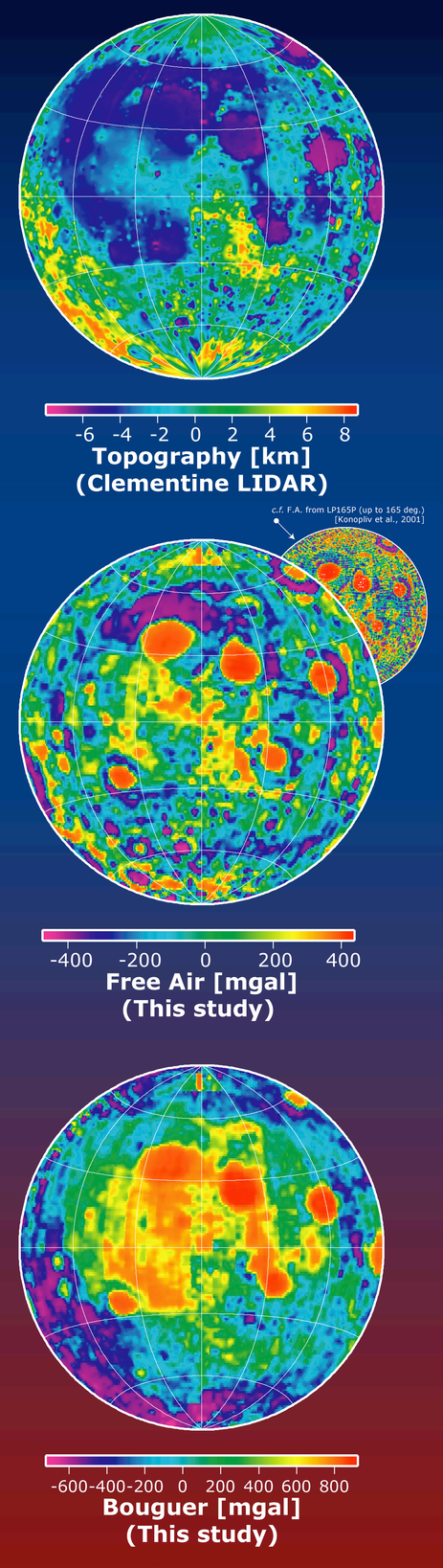




Here we show mass deficits associated with intermediate-sized craters (80-300 km in diameter) on the lunar nearside obtained from the free air (middle) and Bouguer gravity anomaly maps (bottom).

Mass deficits seen in the free air anomaly disappear in the Bouguer anomaly suggesting that the free air anomalies come mainly from topographic lows. This demonstrates that the MOHO topography beneath them is flat, i.e. topography of the craters are supported by lithospheric strength.

The size of each circle corresponds to the age of the crater (the larger the circle size, the younger the age). It seems that there is no correlation between age and compensation state for these craters.



Top: Topography map from the Clementine laser altimetry.

Middle: Free-air gravity anomaly map from the LP LOS acceleration data, with resolution 0.8 deg. x 0.8 deg. , which is equivalent to 225 degree/order harmonics (25 km x 25 km). Signatures of medium-sized (80-300 km in diameter) craters are visible as negative free air anomalies. This map is less noisy than the recent gravity model LP165P [Konopliv et al., 2001].

Bottom: Bouguer anomaly map from the terrain-corrected LP LOS data. Only large structures have topography at MOHO e.g. large impact basins including mascons.

Summary

- From the LP LOS acceleration data (extended mission), we obtained free air gravity anomaly maps of the nearside with resolution equivalent to 225th degree/order without introducing constraints.
- Terrain correction was performed to the LOS data to obtain the Bouguer gravity anomaly map.
- Mass deficits of intermediate-sized craters show little isostatic compensation, consistent with the Nectarian lithospheric thickness of > 100 km [Spohn et al., 2001].