EGU22-9722, updated on 09 Aug 2022
https://doi.org/10.5194/egusphere-egu22-9722
EGU General Assembly 2022

Sensitivity analysis of frequency-dependent visco-elastic effects on lunar orbiters

Xuanyu Hu[1], Alexander Stark[2], Dominic Dirkx[3], Hauke Hussmann[2], Agnès Fienga[4], Marie Fayolle-Chambe[3], Daniele Melini[5], Giorgio Spada[6], Anthony Mémin[4], Nicolas Rambaux[7], and Jürgen Oberst[1]
[1]Institute of Geodesy and Geoinformation Science, Technical University of Berlin, Germany (xuanyuhu@gmail.com)
[2]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany
[3]Faculty of Aerospace Engineering, Delft University of Technology, The Netherlands
[4]Géoazur, Observatoire de la Côte d'Azur, Université Côte d'Azur, France
[5]INGV - Sezione di Sismologia e Tettonofisica (Roma I), Italy
[6]Dipartimento di Fisica e Astronomia "Augusto Righi", Università di Bologna, Italy
[7]IMCCE, CNRS, Observatoire de Paris, PSL Université, Sorbonne Université, Paris, France

Tidal response of the Moon provides crucial insight into the structure and rheology of the lunar interior (Williams et al. 2013). The body deformation subject to forces raised by external objects, most evidently Earth and the Sun, induces a variability of the gravitational field, which is characterized by the Love number, k. This effect may, in turn, manifest itself over time in the perturbed motion of orbiting spacecraft (Konopliv et al. 2013; Lemoine et al. 2013).

For an elastic body the response to the periodic excitation is instantaneous and relaxation times resulting in phase lags of the response are thus neglected. In reality, the lunar interior exhibits a degree of viscosity and dissipates energy through friction, in which case k not only varies with frequency but also comprises an imaginary part that represents a phase lag in tidal response (Williams et al. 2013).

Here, we investigate the signatures of the frequency-dependent Love number in the motion of a lunar orbiter. We formulate the problem following Williams & Boggs (2015), and focus on the variability of five Stokes' coefficients of the second degree effected by k2. The time-varying components are expanded at given characteristic frequencies associated with (linear combinations of) the Delaunay arguments. We make use of the Technical University Delft Astrodynamics Toolbox (Dirkx et al., 2019; https://tudat-space.readthedocs.io/) to investigate the orbit evolution of lunar orbiters, e.g., the Lunar Reconnaissance Orbiter (Mazarico et al. 2018), subject to the time-varying lunar gravitation. Meanwhile, we leverage the analytic theory of Kaula (1966) to illuminate the impact of such specific yet minute perturbations, especially non-short-period variations of the spacecraft orbit (Kaula 1964; Lambeck et al. 1974; Felsentreger et al. 1976).

A particular interest here is in the potential estimability of the frequency-dependent phase lag. Following Dirkx et al. (2016), we conduct a preliminary study of the sensitivity of spacecraft orbit adjustment to the said tidal effects. That is, we investigate if, under which conditions, and to what

degree, the signals in question will be absorbed by the adjustment of initial states or other parameters, a consequence that will effectively prohibit the detection of the tidal effects. The outcome is expected to shed light on the minimum criteria of their estimation and thus instructive to real-world data analysis in the future.

Reference

Dirkx, D., et al. (2016), PSS, 134, 84-95
Dirkx, D., et al. (2019), Astrophysics and Space Science, 364:37
Kaula W.M. (1964), Reviews of Geophysics, 2, 661-685
Kaula W.M. (1966), Theory of Satellite Geodesy, Dover Publications, Inc.
Konopliv, A.S., et al. (2013), GRL, 41, 1452-1458
Lambeck, K., et al. (1974), Reviews of Geophysics and Space Physics, 12, 412-434
Felsentreger, T.L. et al. (1976), JGR, 81, 2557-2563
Lemoine, F.G., et al. (2013), JGRP, 118, 1676-1698
Mazarico, E., et al. (2018), PSS, 162, 2-19
Williams J.G., et al. (2013), JGRP, 119, 1546-1578
Williams J.G., and Boggs, D.H. (2015), JGRP, 120, 689-724