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Satellite gravity-rate observations to uncover Martian plume-lithosphere dynamics

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In the past few decades, Mars-oriented orbiters and landers have allowed to unravel valuable knowledge about Mars' surface and interior. With the InSight mission, seismic waves have indicated the presence of more frequent Marsquakes than assumed before the mission (Banerdt et al. 2020). Moreover, active mantle plume is considered below the Elysium Region (Broquet and Andrews-Hanna, 2023). This raises questions regarding the planet's formation and whether Mars is more geologically active than was considered.

An important milestone in studying the interior of Mars is the recovery of static gravity field models. These models have been accomplished using data from the three recent Mars orbiting missions, namely, Mars Global Surveyor (MGS), Mars Odyssey (ODY), and the Mars Reconnaissance Orbiter (MRO). In addition to the static gravity field, seasonal variations of Mars' gravity field have been observed, providing information regarding the periodic behavior of the polar ice caps (Konopliv et al. 2016, Genova et al. 2016). However, the secular variation of the gravity field and its link to the solid deformation of the planet has been limited studied.

In general, the estimation of the time variations of the gravity field in the very long wavelength can provide insights into activity of the mantle (Wörner et al. 2023). Le Maistre et al., (2023) have studied the spin rate of Mars and its connection to interior mantle flow or atmospheric changes. By analyzing measurements from the Viking and InSight landers, they estimated a long-term change of the rotation rate of Mars and its moment of inertia. The obtained rotation rate change, along with the J2 coefficient variation over one Martian year, suggests factors such as atmospheric changes, glacial rebound of the polar ice caps (GIA, Glacial Isostatic Adjustment), or substantial deep mantle flow. Therefore, decoupling atmospheric signal from solid Mars deformations in the gravity signal is essential.

In this study, we focus on a new way of estimating secular variations of the gravity field of Mars from the available tracking data with an open-source orbit estimation tool: TUDAT (TU Delft Astrodynamics Toolbox). First, we review the state-of-the-art literature on studying the plume-lithosphere interaction and model the gravity-rate signal that would come from mantle flow. Then, we perform a sensitivity analysis for decoupling the secular variations from other signals, such as, the atmospheric density variations and ongoing GIA of the polar ice caps. We do this by simulating one-way and two-way Doppler observations of a Mars-orbiting satellite. We include all possible dynamic forces impacting the satellite. Some of these forces are the static and temporal gravity field, the third body gravitation, the solar radiation pressure, the atmospheric drag, and other forces. For the atmospheric drag, we use the Mars-DTM atmosphere density model that models the static, daily, and yearly variations that affect the drag of the satellite (Bruinsma and Lemoine, 2002). We determined the sensitivity of the estimation process for different parameters including: the initial state, the atmospheric drag and the solar radiation coefficients, and the global vs. arc-wise time varying coefficients. Finally, we perform a correlation analysis of these parameters to determine in which estimation scenario we are able to separate the atmospheric signal from the solid Mars gravity changes. This sensitivity analysis will help in decoupling the gravity-rate signal in order to answer the unresolved question about the activity of the Martian interior.

References:

Banerdt, W.B., Smrekar, S.E., Banfield, D. *et al.* Initial results from the InSight mission on Mars. *Nat. Geosci.* **13**, 183–189 (2020). https://doi.org/10.1038/s41561-020-0544-y

Broquet, A., Andrews-Hanna, J.C. Geophysical evidence for an active mantle plume underneath Elysium Planitia on Mars. *Nat Astron* **7**, 160–169 (2023). https://doi.org/10.1038/s41550-022-01836-3

Bruinsma, S., & Lemoine, F. G. (2002). A preliminary semiempirical thermosphere499 model of mars: Dtm-mars. Journal of Geophysical Research: Planets, 107 (E10). doi: https://doi.org/10.1029/2001JE001508

Genova, A., Goossens, S., Lemoine, F.G., Mazarico, E., Neumann, G.A., Smith, D.E., Zuber, M.T., 2016. Seasonal and static gravity field of Mars from MGS, Mars Odyssey and MRO radio science. Icarus 272, 228–245. http://dx.doi.org/10.1016/j.icarus.2016.02.050

Konopliv, A.S., Park, R.S., Folkner, W.M., 2016. An improved JPL Mars gravity field and orientation from Mars orbiter and lander tracking data. Icarus 274, 253–260. http://dx.doi.org/10.1016/j.icarus.2016.02.052.

Le Maistre, S., Rivoldini, A., Caldiero, A. *et al.* Spin state and deep interior structure of Mars from InSight radio tracking. *Nature* **619**, 733–737 (2023). https://doi.org/10.1038/s41586-023-06150-0

Wörner, L., Root, B. C., Bouyer, P., Braxmaier, C., Dirkx, D., Encarnação, J., Hauber, E., Hussmann, H., Karatekin, Ö., Koch, A., Kumanchik, L., Migliaccio, F., Reguzzoni, M., Ritter, B., Schilling, M., Schubert, C., Thieulot, C., Klitzing, W. v., & Witasse, O. (2023). MaQuIs—Concept for a Mars Quantum Gravity Mission. Planetary and Space Science, 239, 105800. https://doi.org/10.1016/j.pss.2023.105800