NEW ESTIMATES OF SEASONAL SURFACE DISPLACEMENTS AND TIME VARIABLE GRAVITY ON MARS
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Introduction: The mass transport of volatiles on Mars represents a modern atmospheric process that interacts with the interior of the planet by acting as a load on the lithosphere. Much like on Earth, as mass is redistributed across the planet, the surface responds in a complex manner becoming displaced downwards or upwards. The magnitude and extent of displacement is dependent upon the properties of the load and rheology of the planet. Based on new estimates of the height variation of the seasonal polar caps (SPCs), we predict local displacements of up to tens of millimeters with a strong degree 1 signal throughout the Martian year. The long-wavelength portion of the displacement is still notable, with a magnitude of a few millimeters, located away from the seasonal polar cap and where we could realistically measure it. We also model the expected time variable gravity signal this causes. Future measurements of this displacement could be used to help elucidate the rheology of the mantle and crust of Mars, using this process as a probe into the elastic and viscous properties of the planet.

Procedure: To model displacements on Mars from seasonal volatile transport, we use a software package called LoadDEF that was designed to model surface displacements from ocean tidal loading on Earth [1]. This process is not unique to Mars, and the software has been validated for use on other planets. This program uses Green's functions derived from Load Love Numbers (LLNs) convolved with a surface mass load to determine the elastic response of a planet to surface loading. LLNs are dependent upon the interior rheologic profile of a planet and represent how a planet responds to a perturbation. With LLNs this perturbation comes from a surface mass load; h' represents the change in radial displacement and k' represents the perturbation in the gravity field. We use three interior profiles of the rheology of Mars that have been found using different methods to judge the expected difference in displacement given different properties and determine the resolution needed to detect differences in the displacement. The profiles were found using a geodynamic inversion (MD), a geophysical inversion (AK), and a seismic inversion (CD) [2-4]. We use the most recent model of changes in the height variations of the SPCs to forward model this process [5-8]. These height variations have a higher precision compared to previous studies and include longitudinal variations. We thus use these temporally and spatially heterogeneous height variations in addition to the derived density of the deposits as the surface mass load inputs into LoadDEF. We also consider the effects of tidally induced displacements from the Sun and Phobos.

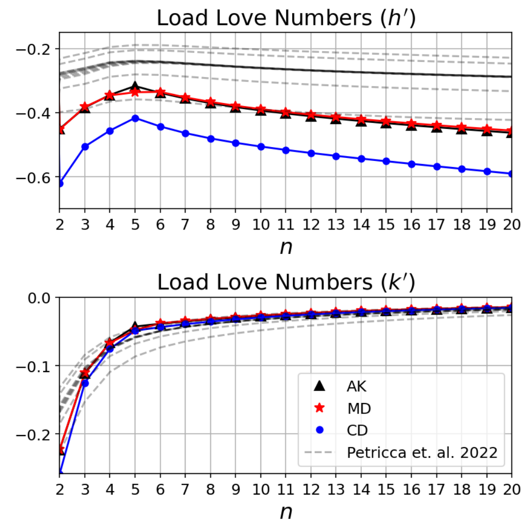

Figure 1: LLNs calculated up to degree 20 to compare with previous results [9]. Note the similarities between interior models used for k', but the large differences in values of h'. If h' is indeed more sensitive to interior profile than k', then the measurement of the displacement would provide a tighter constraint on interior properties than gravity studies that simply constrain k'.

Results: Figure 1 shows our LLNs results, comparing it to a previous study that investigated LLNs for Mars. There are large similarities in our LLNs for the three profiles, but h' shows substantial variability, and is much more sensitive to the assumed interior model than is k'. Therefore, we show that h', and thus the radial displacement, is much more sensitive to the interior rheologic profiles than k'. Thus, constraining h' is additionally important to k' in resolving interior structure from Love numbers. Figure 2 shows the modeled expansion of the temporal changes in the areoid generated from the height variation models we use compared to observations of time-variable gravity coefficients [10]. The odd zonal coefficients match well with measured values of these coefficients from orbital tracking data. However, the even zonal coefficients are much different in both shape and magnitude. Notably, our C_{20} and C_{40} terms are much higher in magnitude than measured values. Our vertical displacement predictions are shown in figure 3. Although we have only plotted the results for the maximum extent of the northern SPC for space rea-

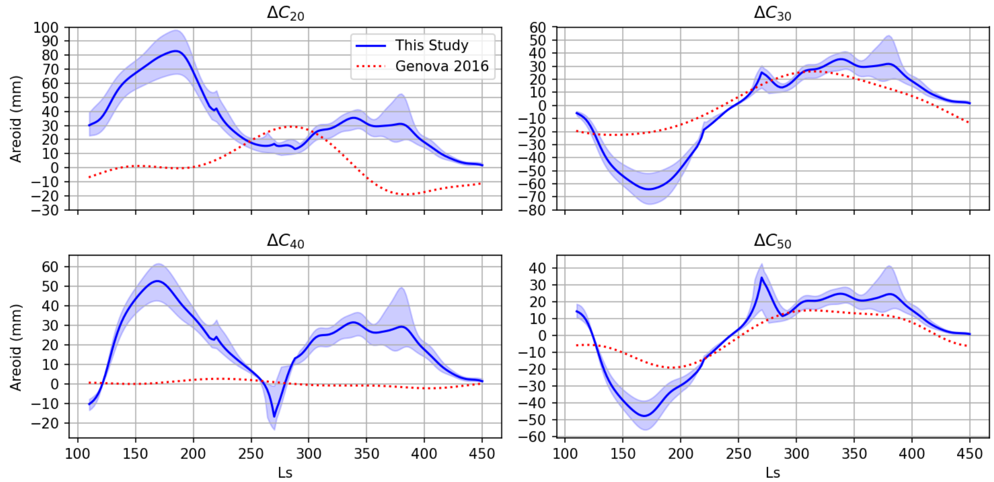

Figure 2: Modeled time variable areoid zonal coefficients calculated from the height variations from Xiao et. al. 2022 (blue), and observed time variable areoid zonal coefficients found by Genova et. al. 2016 (red).

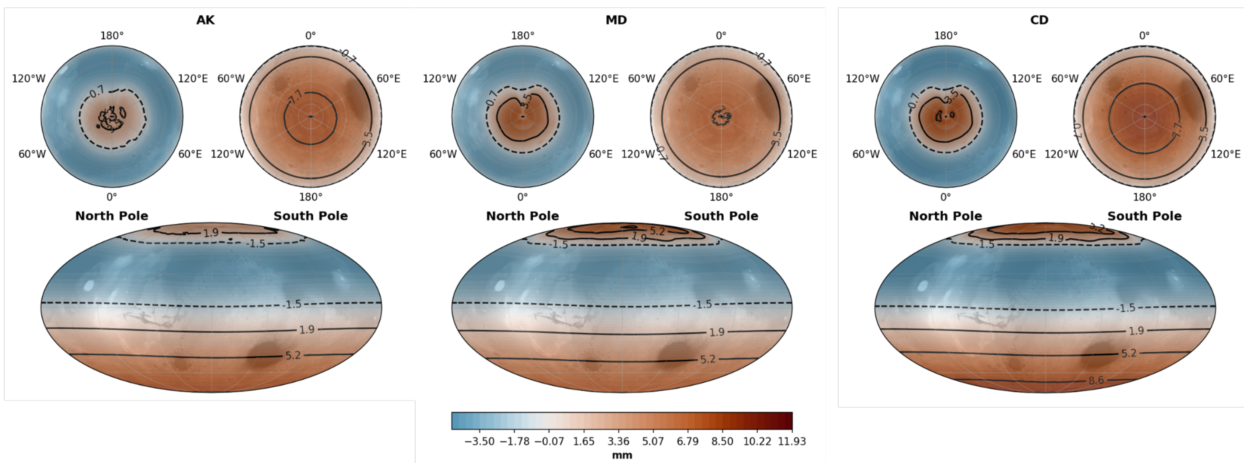

Figure 3: Plotted is the vertical displacement expected from each interior model. We have plotted the results for L_s=360 which is roughly the maximum extent of the northern SPC. Positive is downward displacement.

sons, we see a degree 2 pattern emerge that reflects the growth and shrinkage of each SPC. The displacements from the southern SPC are roughly twice the magnitude of the ones from the northern SPC, which is consistent with what we expect from the height variations being roughly twice as high in the southern SPC. Each interior model predicts similar magnitudes and patterns of displacement, differing by a few millimeters at their maximum and minimum.

Implications for Landed and Orbital Missions: Currently, our predicted deflection of mms–cms is not detectable in either orbital or landed mission data. However, this seasonal surface deflection could be plausibly observed by future missions. A future landed geodetic instrument would need precision of centimeters to millimeters in order to observe this deflection and constrain basic properties of the Martian interior, and precision of submillimeters in order to distinguish between the different interior models shown in this work.

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