QUANTIFYING LITHOSPHERIC DEFLECTION CAUSED BY SEASONAL MASS TRANSPORT FROM THE POLAR LAYERED DEPOSITS ON MARS N. L. Wagner[1], P. B. James[1], A. I. Ermakov[2], and M. M. Sori[3]. [1]Baylor University, Department of Geosciences, One Bear Place #97354, Waco, TX 76798, USA (nick_wagner2@baylor.edu), [2]Space Sciences Laboratory, University of California, Berkeley, [3]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University.

Introduction: The polar layered deposits (PLDs) on Mars represent one of the most active areas of mass transport on the planet. Measurements of time varying topography from MOLA has showed us that the PLDs change in height on the order of meters seasonally [1]. It's estimated that up to 10^{15} kg of water and CO_2 ice is sublimated and subsequently deposited during the summer and winter on the respective hemisphere's PLD [2]. This amount of ice is likely significant enough to cause lithospheric deflection to occur on the timescale of the mass transport, i.e. on an seasonal basis. In a recent gravity model, the amount of mass transported was independently solved for, allowing us to fully model the effects on the lithosphere that result from this mass transport [2]. In this study we quantify the expected deflection of the lithosphere from the annual loading signal caused by this process. Future measurements of this deflection from a landed instrument could be used to constrain the present day elastic thickness of the lithosphere. A measurement of this value would provide insight into the modern thermal and rheological composition of the martian interior. This present day snapshot of the interior could then be used to infer the evolution of the lithosphere through the life cycle of the PLDs.

Procedure: We treat the flexural theory of the problem using two established methods: thin-shell theory and load Love numbers (LLNs). Thin-shell theory implies the interior of Mars is inviscid beneath the elastic thickness of the lithosphere. LLNs imply that Mars is elastic all the way to the core. The time scales considered here are likely too short for any viscous relaxation to occur, and portions of Mars that would be considered ductile over geologic timescales would behave elastically. LLNs will then likely provide more a realistic estimate of the seasonal displacement expected. Thin-shell theory will still provide useful results for us; we will consider any results from thin-shell theory as upper bounds on the deflection expected. It will also be more appropriate to consider thin-shell theory as we continue this study as we investigate mass change through obliquity cycles.

We model the load as a cylinder centered at the north pole. The height of the load is solved for by using constraints of the density, mass, and radius. By using a mass of 10^{15} kg, density of 900 kg/m^3, and a radius of 500 km, the height of the material deposited is roughly 1.5 meters [1,2]. This height is consistent with estimates of height changes of the northern PLD from MOLA topography [1].

For the thin shell formulation, we assume an effective elastic thickness (T_e) of 300 km, an elastic modulus of 50 GPa, and a Poisson's ratio of 0.25. We use the constant T_e special case of Beuthe's formulation [3]. For the LLN modeling we use the open source Python software package LoadDEF [4]. While this package is used for seasonal loading problems on Earth, such as tides or water transport, it can easily be adapted for use on Mars. For this formulation we used three different interior models of Mars based on three different inversion techniques, described as a "geophysics", "geodynamics", and "seismic" model [5]. These interior models are best constrained at the landing site on InSight, which is representative of the northern lowlands. Because of this we chose to only explore the expected deflection from the northern PLD for this abstract. Future modeling investigating the deflection of the southern PLD will have to make modifications of these interior models to reflect the change in the upper 25-50 km or so of the lithosphere [6].

Results (Thin-Shell Theory): Figure 1 shows the deflection of the load for the thin-shell theory case. The lithosphere experiences deflections in excess of 200 mm directly beneath the load, but that value decreases sharply with distance from the load. Directly at the edge of the PLD, this model predicts deflections of around 100 mm. A broad flexural bulge develops south of about 40 degrees North, but it only has a magnitude of about 4 mm. As stated before, because of the elastic nature of the problem, we interpret these results as upper bounds on this seasonal deflection. We note that this treatment may be better suited then LLNs to investigate the history of geodynamic interactions between the lithosphere and the PLDs as these deposits have grown, shrunk, and migrated with obliquity cycles [7].

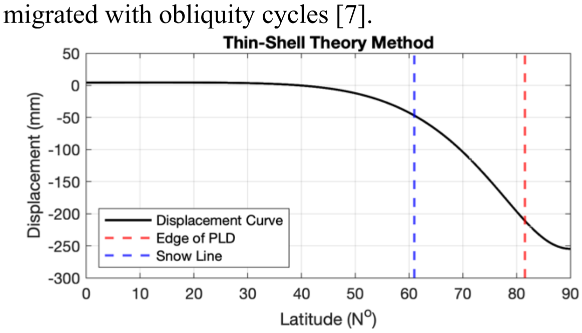

Figure 1: Plot of deflection as a function of latitude. Also plotted is the edge of the load, i.e. the cylinder load we're modeling and the "snow line" or where the seasonal snow depth is below 10 centimeters [1].

Results (LLNs): Figure 2 shows the deflection of three different interior models using the LLN method. These models represent different inversions using differing combinations of geodetic, gravity, and seismic data. We point the reader to [5] for more information about the assumptions of each model. Differences in the displacement curves between the three interior models were minimal, with the maximum displacement beneath the load ranging from 100–115 mm. However, the slope of displacement is much shallower compared to the thin-shell results, with displacement values greater than 5mm occurring as low as 20 degrees North. Positive displacements either occur near the equator, or in the southern hemisphere, depending on the interior model used.

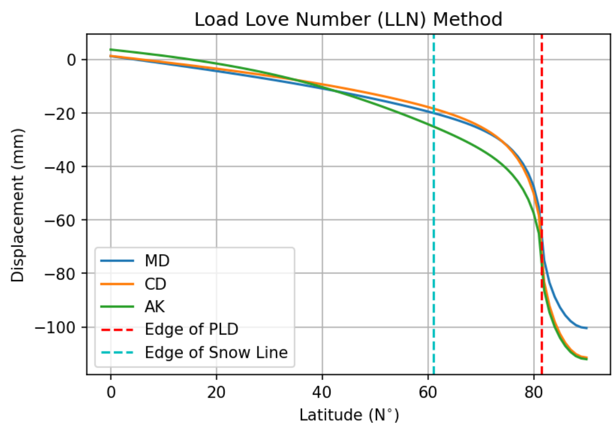

Figure 2: Plot of deflection as a function of latitude. “MD” is the geodynamical model, “CD” is the seismic model, and “AK” is the geophysical model. More information about these models can be found in [5]. Also plotted is the edge of the load, i.e. the cylinder load we are modeling, and the “snow line” or where the seasonal snow depth is below 10cm [1].

Discussion and Future Work: The results from both these treatments are fairly similar, with displacements of order cms. The results from LLNs are also on the same order as previous results using LLNs [8]. Maximum displacements from thin-shell theory are larger in magnitude for high latitudes, with the shape as a function of distance from the load being in line with what we expect. These results show the deflection when material is deposited, and we should expect to see an equal amount of rebound when the material is removed during the spring and summer. Thus, this magnitude of deflection should then occur twice a year: once as the material is removed, and then again when its redeposited. This annual signal is convolved with the concurrent deflection of the opposite pole. To more thoroughly tease out the seasonal signal, we plan on modeling the deflection of both poles simultaneously. In addition to this, we will modify the interior models resolved by InSight to be more representative of the southern hemisphere’s composition and thickness.

There are many caveats to these models. They assume no topography outside the load and are calculated in the center of mass reference frame. This assumption means that these results don’t incorporate effects from Tharsis, the hemispheric dichotomy, or any other long wavelength topographic or structural heterogeneities. Considering the load, our assumption of the shape of it is a simplification of the lateral extent of the load. In reality the edge of the load will be tapered out to the snow line instead of being confined as a cylinder of uniform thickness over the PLD. In ongoing work, we are implementing a cone-shaped load with the top cut off to represent this shape more realistically. This snow line is important, as it guides where we might be able to actually measure this displacement without the snow smearing out the signal from loading or negatively affecting any landed instrument at this latitude. The snow line used in this work, 61 degrees north, is taken from [1] and represents where the seasonal snow height is below 10 centimeters. Despite these caveats, the results are promising, as there is a significant amount of displacement occurring from this loading, both with the thin-shell assumption and the LLN method. More so, there’s a significant amount of flexure occurring below the snow line.

It should be stated that these results are constitutive of the annual changes in mass of the PLDs, and currently don’t have implications for the discussion of the static lithospheric deflection of the PLDs. In the future, however, we plan to investigate what these models imply for changes in the mass and location of the PLDs during different scale obliquity cycles. Therefore we plan to model how these obliquity cycles have affected the loading history of the PLDs over time. These longer period loading cycles will incorporate more of, what is considered presently, the static portion of the deflection caused by the PLDs [7,9]. As what is called static versus seasonal will change depending on what timescale is being discussed.

References: [1] D. E. Smith, et al. *Science*, 294(5549):2141–2146, 2001. [2] A. Genova, et al. *Icarus*, 272:228–245, 2016. ISSN 10902643. [3] M. Beuthe. *Geophysical Journal International*, 172(2):817–841, 2008. [4] H. R. Martens, et al. *Earth and Space Science*, 6(2):311–323, 2019. [5] S. C. Stahler, et al. *Science*, 448(July):443–448, 2021. [6] H. R. Martens, et al. 121(5):3911–3938, 2016. [7] J. Laskar, et al. *Letters to Nature*, 419:375–377, 2002. [8] L. Metivier, et al. *Icarus*, 194(2):476– 486, 2008. [9] R. J. Phillips, et al. *Science,* 320(5880):1182-1185, 2008