GRAVITATIONAL CONSTRAINTS ON MID-LATITUDE ICE… AND THE NEED FOR MORE GRAVITY DATA AT MARS

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Introduction: Recent analysis of radar data from the Mars Reconnaissance Orbiter (MRO) has suggested that the mid-latitudes of Mars contain thick (tens to over 100 meters) sheets of buried excess ice [1, 2]. This inference is supported by geomorphologic analysis [3], high-resolution images [4], and neutron data [5], although alternative interpretations of the radar data may also be possible [6]. The presence of these ice sheets is important for a variety of scientific reasons, such as understanding the exchange of water between mid-latitude reservoirs and the larger polar deposits [7]. Additionally, any near-surface mid- or low-latitude ice represents a relatively accessible inventory of water that may be a critical resource for future human exploration or habitation of Mars.

Here, we use gravity to constrain putative buried mid-latitude ice sheets on Mars. Gravity is a powerful tool to study subsurface crustal structure, and while it has been previously used to quantify polar ice on Mars [8–10], it has not yet been considered in the analysis of mid-latitude ice sheets. We focus our study on the proposed ice sheets at Arcadia Planitia [1] and Utopia Planitia [2]. Water ice has substantially lower bulk density than the average Martian crust, and the presence of ice sheets should thus create a negative Bouguer gravity signature. If this signature can be confidently detected in the regions of Arcadia and Utopia Planitia, it can be used to estimate the volume of subsurface ice. Alternatively, the lack of an identifiable signature would imply an upper limit on the volume of ice, which depends on the precision of the known Martian gravity field.

Analysis: We consider the most recently published static gravity field of Mars, GMM-3, that has been inferred by radio tracking of Mars-orbiting spacecraft [11]. In our regions of interest, the local degree strength (the maximum spherical harmonic degree in the gravity field which has power greater than uncertainty) is ~80. This degree strength corresponds to a half-wavelength resolution of 133 km, and the proposed buried ice sheets in Arcadia and Utopia Planitia have lengths between 500–1100 km. We therefore argue that the ice sheets would likely be laterally extensive enough to analyze in GMM-3, and any gravitational signature or lack thereof constrains their thicknesses.

Gravity solutions are inherently non-unique. In the absence of constraints from other datasets or reasonable geophysical assumptions, observed gravity anomalies have infinite possible mathematical interpretations. Mars commonly has Bouguer anomalies of order 100s of mGals. Therefore, it is important to not simply interpret any negative Bouguer anomalies as evidence of buried ice; rather, plausible evidence comes in the form of locally low Bouguer anomalies that are spatially correlated with geological, radar, or thermal evidence of subsurface ice sheets.

We model the gravitational anomaly that would be expected from a buried ice sheet. We model the ice as a rectangular prism with an upper surface at the Martian surface and a lower surface defined by the ice thickness T. The Bouguer gravity anomaly from such an ice sheet is dependent upon the ice density ρ_i and the crustal density ρ_c, and given by equations 1–3 in [12] (although for this simple model, the anomaly is effectively the same as that given by a mass sheet approximation). Assuming ρ_i = 917 kg/m^3 and ρ_c = 2582 ± 209 kg/m^3 [13], the amplitude of the Bouguer gravity anomaly above the ice sheet is shown in Fig. 1 for various values of ice thickness and the density of the underlying crust.

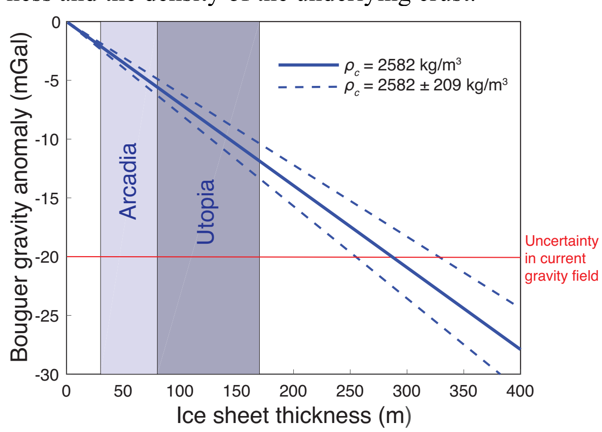

Figure 1. Modeled gravity anomalies from buried ice sheets as a function of their thickness and the Martian crustal density. Overlain are the proposed thicknesses of ice sheets in Arcadia (30–80 m) [1, 7] and Utopia (80–170 m) [2] Planitia, and the uncertainty in the inferred Martian gravity field [11] in those regions.

We do not observe any locally low Bouguer anomalies in Arcadia or Utopia Planitia that are spatially correlated with areas of proposed subsurface ice. However, the plausible gravity anomalies associated with buried ice sheets on Mars are relatively small. For example, a pure ice sheet that is 500 m thick (which is thicker than expected) would create a Bouguer anomaly of -35 mGal, and the most likely solutions based on current thickness estimates yield <10 mGal signatures. Additionally, the GMM-3 field [11] has uncertainty of nearly 20 mGal in these regions, so this result is interpreted as evidence that any subsurface ice is < 330 m thick (Fig. 1). Thicker ice sheets would have produced an observable gravity anomaly.

This result scales inversely with the difference in density between the putative ice and the surrounding crust; for example, if the ice is not pure but instead contains 10% dust (that has density 2500 kg/m^3) mixed in, the density difference between the ice and surrounding crust decreases, and the upper limit on the ice thickness is instead 370 m.

Our methodology described above represents analysis performed on gravity data in the spatial domain. Our ongoing work that will be presented at this meeting involves analysis performed on gravity data in the spectral domain [e.g., 9]. A spectral analysis of gravity reveals variations in the gravity anomaly at various wavelengths, an important property because different wavelengths are sensitive to different ranges of depths in the Martian subsurface.

A need for more gravity data! Currently, gravity science at other planets in our solar system is fundamentally lagging behind gravity science in the Earth-Moon system. At the Moon, measurement of the static gravity field to extremely high resolution with spacecraft-to-spacecraft tracking [14] has provided an unprecedented look at how planetary crusts form and evolve [15]. On Earth, similar mission architecture, plus gradiometry [16], have measured the time-varying gravity field to enable the study of dynamic processes like hydrological cycles and climate change. Similar advances can be made at Mars with new missions that adapt these mission architectures outside the Earth-Moon system, fly at lower altitudes, and/or develop other technologies.

Specific to this work, new gravity data could be used to support or refute the proposed water ice deposits at Arcadia or Utopia Planitia (or at other locations), thereby elucidating Martian climate change and mapping resources to enable human exploration. At the moment, uncertainty in the Martian gravity field is inconveniently maximized in the region of the possible Arcadia and Utopia ice sheets (Fig. 2). This locally high uncertainty is the result of a combination of MRO's polar orbit (more passes over high latitudes) and elliptical orbit (closer passes over the southern hemisphere), leaving the northern mid-latitudes as the area with the least precise gravity field. This deficiency can be realistically rectified with future missions or instruments. Furthermore, increasing the degree strength of the Martian gravity field will allow planetary scientists to isolate anomalies in the upper crust and thereby estimate ice volume more robustly.

We have compiled a list of which goals and objectives could be addressed by new gravity data at Mars. Investigations into the proposed buried ice sheets at Arcadia and Utopia Planitia would address at least 3 goals and 5 objectives of Mars science as defined by the Mars Exploration Program Analysis Group (MEPAG), at least 5 questions as defined by the Ice and Climate Evolution Science Analysis Group (ICESAG), and at least 2 objectives as defined by the Next Orbiter Science Analysis Group (NEXAG). Other benefits of a new gravity field hold similar promise for supporting Mars polar science. For example, more precise gravity fields would allow for scientific investigations into the distribution of buried carbon dioxide ice deposits, addressing several MEPAG and ICESAG objectives, while also supporting future entry/descent/landing of future robotic or crewed missions. New missions can elevate gravity science from only being a geophysical tool, enabling a multitude of other polar-science-related disciplines, including geomorphology, atmospheric science, hydrology, and human exploration.

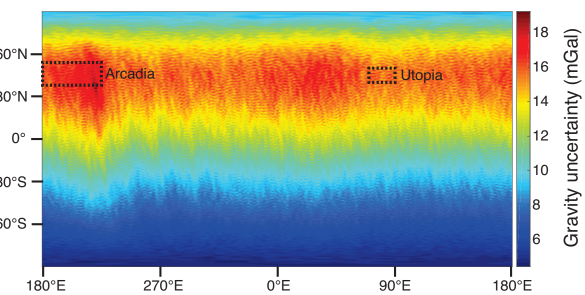

Figure 2. Uncertainty in the currently known Martian gravity field [11], with locations of proposed ice sheets in Arcadia [1] and Utopia [2] Planitia.

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