MARS SUBSURFACE HYDROLOGY IN 4D. V. Stamenković[1], A.-C. Plesa[2], D. Breuer[2], M. Mischna[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA. [2]DLR Institute of Planetary Research, Berlin, Germany.

Introduction: The Martian subsurface has had and still has the potential to enable environments with stable liquid groundwater. The possibility of such liquid underground waters has gained more interest since the announcement of a possible subsurface lake beneath the South Polar Layered Deposits on Mars with MARSIS [1]. The temperature at the base of these polar deposits at 1.5 km has been estimated to be ~205 K, which would require large amounts of dissolved salts (likely Ca- or Mg-perchlorates) to sufficiently reduce the freezing point of water.

Due to attenuation, MARSIS and SHARAD have generally great difficulties to detect groundwater beneath a depth of a few hundred meters, particularly at an aquifer horizontal scale of less than a few tens of km and away from the polar caps. As estimates of the average groundwater table are generally far beyond a depth of 1 km [2], it is possible that Martian groundwater might be much more widespread but has so far not just remained undetected but was rather undetectable.

Methods: We calculate the depth where the theoretical cryosphere would become pure liquid water (D_{H2O}) with 4D (three in space and one in time) interior models of Mars that self-consistently compute the subsurface thermal profile, porosity, and permeability as a function of location and planet age across the last 4.5 billion years. The two geodynamical models used are (A) a 3D spherical full mantle convection [3] and (B) a parameterized thermal evolution model both coupled to a 3D crustal model that is compatible with today's gravity and topography data. The spherical interior full mantle convection model explicitly considers both lateral variations of the crustal and mantle heat flow contributions, which can lead to regional perturbations that can shift the groundwater table locally closer to the surface. The advantage of the parameterized model on the other hand is the computational speed. Hence, it can test a wider parameter space for the initial conditions, rheology, subsurface rock composition, thermal properties of crust and mantle, radiogenic heat source distribution, and groundwater chemistry (variable amounts of Ca- and Mg-perchlorates and chlorides as well as sulfates).

Both geodynamic models are coupled on the surface to a general circulation climate model (GCM) that computes annually averaged surface temperatures for modern-day Mars. The GCM used is the Mars Weather Research and Forecasting, MarsWRF model. MarsWRF is a global model based on the terrestrial mesoscale WRF model (see [4]-[6]) and is a Mars-specific implementation of the PlanetWRF GCM [7], accounting for a changing climate with variable planet obliquity through time.

Results: D_{H2O} depends on surface temperature, geothermal gradient (affected by local crustal thickness, density, thermal conductivity, and crustal enrichment of radiogenic heat sources), and water chemistry (e.g., brines).

The effect of subsurface heat flow on groundwater table depth is mainly evident in basins, along the dichotomy and in volcanic provinces, whereas surface temperatures give general water table depth trends with latitude (see Figure 1).

The present pure liquid water table can be as shallow as 2 km beneath Tharsis (larger surface temperatures and larger subsurface thermal gradient) and as deep as 20 km in the northern polar regions (cold surface and small subsurface thermal gradient).

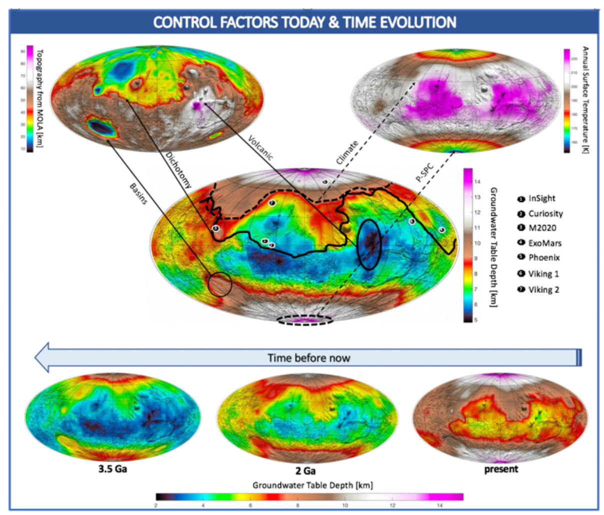

Figure 1: The upper image shows for one selected standard run the depth of the theoretical cryosphere/liquid water table interface (D_{H2O}), below which pure groundwater could exist today. This depth depends on surface temperature and on local heat flux. The lower image shows how the cryosphere/liquid water table interface changed through time assuming no changes in crustal thicknesses, crustal properties, or climate (an unrealistic assumption that will later be released).

The present pure water table for the South Polar Layered Deposits (PLD) is about 1.5 x shallower than for the North PLDs due to a combination of differences in crustal thicknesses and surface temperatures. The average water table depth increased within the last 4.5 billion years by a factor of 2-3.5.

We find using our spherical full mantle convection models that plumes have a small effect on the cryosphere/liquid water table interface as shown in Figure 2.

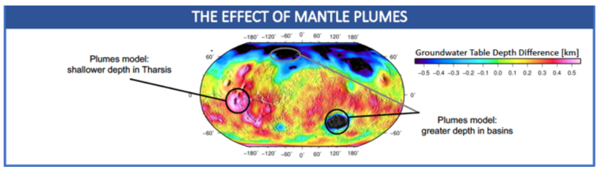

Figure 2: Map of the differences between a 3D spherical full mantle convection model with and without plumes.

Our results suggest that on modern-day Mars the depth of potential groundwater follows a distribution that reflects the combined effects of crustal thickness and surface temperature variations. Variations between equatorial and polar region identified in our models are in agreement with previous studies [e.g., 2] but are modulated by local geothermal heat fluxes. Equatorial regions with large surface heat flow such as the ones in the Tharsis province and in Terra Cimmeria show a depth of the pure liquid groundwater of a few kilometers (see Figure 1). Addition of salts that lower the freezing point of water and/or a lower effective thermal conductivity that would lead to higher temperatures due to the blanketing effect can bring liquid subsurface water towards depths smaller than one kilometer. For now, we assume the modern-day Martian climate and topography but plan to extend this work to account for obliquity-driven climate change, variable topography (e.g., pre-Tharsis), and to expand our framework beyond ground water stability to groundwater flow. Finally, we will discuss implications for detecting such groundwaters in the near future with electromagnetic tools.

References: [1] Orosei et al. (2018) Science, 10.1126/science.aar7268. [2] Clifford et al. (2010) JGR, doi:10.1029/2009JE003462. [3] Plesa et al. (2016) JGR, 10.1002/2016JE005126. [4] Michalakes et al. (2004) Proceedings of the 11th ECMWF Workshop on the Use of High Performance Computing In Meteorology, edited by G. Mozdzynski, 156–168. [5] Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers (2005) NCAR Tech. Note 468+STR, Natl. Cent. for Atmos. Res., Boulder, Colo. [6] Skamarock, W. C., and J. B. Klemp (2008) J. Comp. Phys., 227, 3465–3485. [7] Richardson, M. I., A. D. Toigo, and C. E. Newman (2007) J. Geophys. Res., 112, E09001, doi:10.1029/2006JE002825.

Acknowledgments: This work was performed in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.