**TEMPORAL AND SPATIAL VARIATIONS OF HYDROGEN CONTENT IN THE MARTIAN SHALLOW SUBSURFACE.** A. J. Segura[1], G. M. Martinez[2] and M. D. Smith[3], [1]University of Murcia (antoniojoaquin.segura@um.es), [2]Lunar and Planetary Institute/USRA, TX, USA, [3]NASA Goddard Space Flight Center, MD, USA.

**Introduction:** The Neutron Spectrometer (NS) on board the Mars Odyssey mission (MO) [1] has been surveying the shallow subsurface (~first meter) of Mars for the last two decades, successfully mapping its hydrogen content and distribution [2]. Measurements from NS have been used to identify the main water reservoirs at low and equatorial latitudes [3], and have sparked discussions about the presence of liquid water on present-day Mars [4].

Due to the lack of a major global magnetic field and the thin Martian atmosphere, cosmic rays collide with atoms in the Martian soil, generating neutrons which scatter and collide with other atoms. The flux of neutrons leaking from the surface is inversely related to the hydrogen content of the soil, and thus it can be used to map the amount and distribution of hydrogen on Mars. MO/NS collects neutron fluxes in three consecutive energy bands: thermal (0-0.3 eV), epithermal (0.3 eV-700 keV) (ECR), and fast (0.7-5 MeV) neutron ranges. Among these, epithermal neutrons are more useful in interpreting water abundance (Fig. 1) as they are less sensitive to variations in the soil's amount of heavy elements.

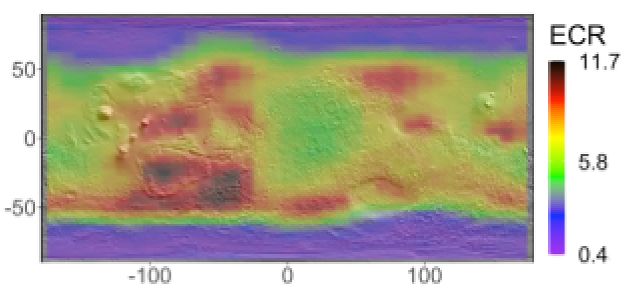


**Figure 1.** Global map of epithermal neutron counting rates binned into 5°×10° spatial pixels and averaged from the beginning of the mission in February 2002 (MY 25 at Ls 329º) to December 2018 (MY 34 at Ls 316º).

MO/NS measurements are sensitive to the hydrogen content of the soil, but not to the type of molecular association of such hydrogen. Potential hydrogen carriers in the Martian regolith include buried water ice, structural water bound in salts (chemisorbed water), and water molecules adsorbed on the surface of soil grains and minerals [5].

To the best of our knowledge, seasonal variations in ECRs have not been analyzed to date. Such variations can be helpful to identify in which form the hydrogen is present in the shallow subsurface (e.g., water ice). Our goal here is to identify the presence of water ice at mid-latitudes by detecting statistical seasonal variations in the ECR signal.

**Methodology:** We retrieved the MO/NS data set available in NASA's PDS and then stored it in a No-SQL local database to simplify analyses. First, we discarded pixels with the presence of $CO_2$ frost. Then, we calculated the subseasonal and climatological means of the epithermal counting rates for each 5º×10º bin ($S_x$ and $C$, respectively), where the former represents an average over a defined range of solar longitude (Ls) during the period x and the latter over the entire span of the data set.

We defined the epithermal counting rates relative subseasonal variation ($RV_x$) as:

$$RV_x = \frac{S_x - C}{C} \quad (1).$$

We only analyzed ECRs corresponding to mid-latitude values between -55º and 55º. These values have a homogeneous standard deviation and a normal distribution.

T-test is a statistical technique to compare two normal distributions with similar standard deviations. If the T-test returns a p-value lower than 0.05, then the distributions are different (both are normal, but they have different means). As an example, Fig. 2 shows $RV_{0-90}$ distributions for Hellas (latitude between 50ºS and 28ºS and longitude between 40ºE and 95ºE) and mid-latitude Mars (between 55ºS and 55ºN).

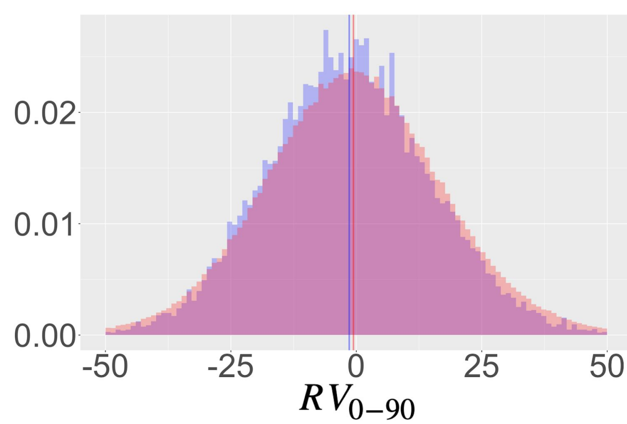


**Figure 2.** Hellas distribution is shown in transparent blue, while data in latitudes between 55ºS and 55ºN is shown in red. The colored vertical lines represent the mean of each distribution. These two distributions have a T-test value lower than 0.05 therefore they are normal distributions with different mean.

We calculated the T-test p-value, $t_x(b)$, between mid-latitude Mars values of $RV_x$ and all values of $RV_x$ in the 5º×10º bin 'b'. Then, we calculated a threshold function, $s_x(b)$, to determine areas where the seasonal variation in ECRs was significant. Specifically, we defined the difference between the means of mid-latitude Mars and the bin 'b' during the Ls period x as:

$$d_x(b) = <RV_x>_{bin} - <RV_x>_{Mars} \quad (2)$$

Finally, we defined the threshold function as:

$$s_x(b) = \begin{cases} 0 & if \;\; t_x(b) > 0.05 \\ 1 & if \;\; t_x(b) < 0.05 \;\; \& \;\; d_x(b) > 0 \\ -1 & if \;\; t_x(b) < 0.05 \;\; \& \;\; d_x(b) < 0 \end{cases} \quad (3)$$

**Results:** As an example, Fig. 3 shows the function $s_x(b)$ over the Ls periods 0º-90º (top) and 180º-270º (bottom) using the following color code: grey represents areas with no significant variation, green with significant negative variation (increase in hydrogen content), and red with significant positive variation (decrease in hydrogen content). A similar spatiotemporal behavior is found if shorter Ls periods are used.

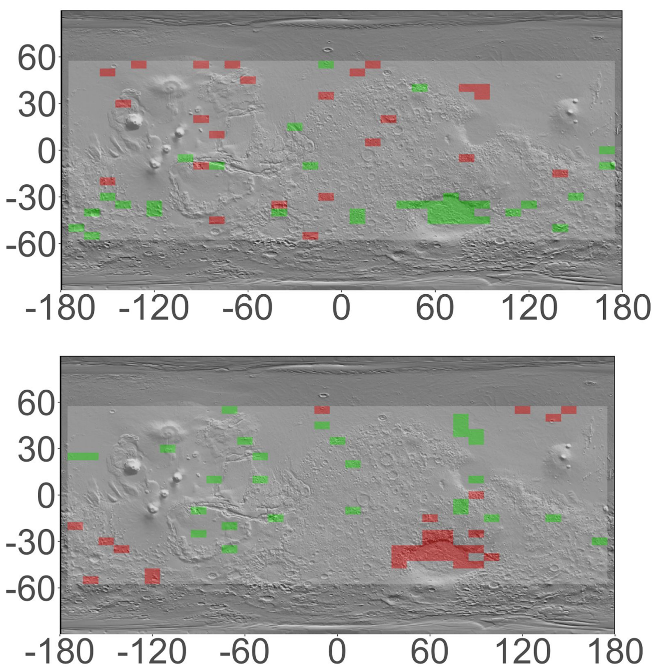


**Figure 3.** Map indicating areas with significant seasonal variations in ECRs during Ls periods 0º-90º (top) and 180º -270º (bottom). Green/red indicates negative/positive departures (increase/decrease in hydrogen content).

Although Hellas is not the only region with significant variations in ECRs (Fig. 3), it is the only mid-latitude region in which multiple, adjacent bins undergo a significant variation throughout the year. We have performed sensitivity studies by varying the bin size while maintaining a statistically-large number of measurements per bin. Results from these studies showed that Hellas is the only region with a significant number of adjacent bins undergoing significant subseasonal variations.

The relation between the seasonal variation in ECRs and ground temperature at Hellas, shown in Fig. 4, indicates that the lowest/highest ground temperatures occur at a similar time to the largest negative/positive departures of ECR with respect to the mean (i.e., increase/decrease in hydrogen content), suggesting that water ice might form in the shallow subsurface of Hellas in southern fall, and then starts sublimating in southern spring.

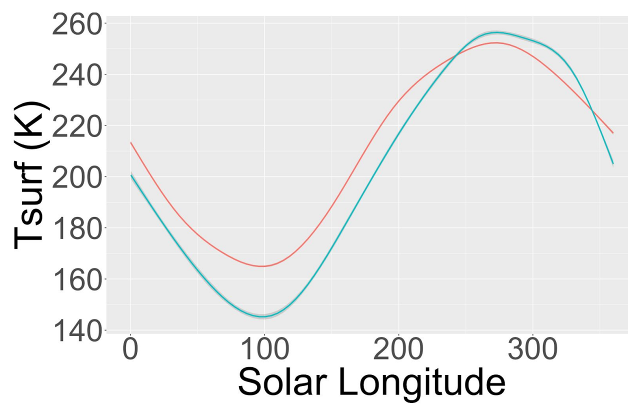


**Figure 4.** Seasonal evolution of ground temperature at Hellas as retrieved from TES (blue) and THEMIS (red).

**Conclusion:** There is a statistical significant seasonal variation of epithermal counting rates in Hellas Planitia. This variation indicates an increment of hydrogen content during southern fall and winter, and a decrease during southern spring and summer. This variation is correlated with temperature, supporting the hypothesis that shallow subsurface water ice might form at Hellas.

**Acknowledgments:** We have used MO/NS Derived Neutron Data (DND) from Planetary Data System (PDS) to produce our results.

**References:** [1] Russell, C. T. (Ed.) (2004) *2001 Mars Odyssey*. Springer Science & Business Media. [2] Maurice et al. (2011) *Journal of Geophysical Research,* 116(E11). [3] Wilson, J. T., et al. (2018) *Icarus*, 299, 148–160. [4] Bhardwaj, A., et al. (2019) *Reviews of Geophysics*, 57(1), 48–77. [5] Jakosky, B., et al. (2005) *Icarus*, 175(1), 58–67.