DIURNAL STORAGE AND RELEASE OF LUNAR SUBSURFACE WATER IN THE CLAVIUS REGION.
P. Reiss[1], T. Warren[2], E. Sefton-Nash[1], R. Trautner[1], [1]European Space Agency, ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands (philipp.reiss@esa.int), [2]Atmospheric, Oceanic and Planetary Physics Department, University of Oxford, Oxford, UK.

Introduction: Previous work [1-3] has shown that diurnal surface temperature variations in principle enable thermal pumping of water into the lunar subsurface. While this process has previously only been investigated from the perspective of long-term storage of water/ice at greater depths, it can also be a relevant mechanism for temporary storage. Water delivered to the lunar surface is trapped during night and released during the subsequent day, depending on the thermal environment, the bonding mechanisms and the migration depth. We used the Oxford 3D thermophysical model [4] to simulate heat fluxes on the lunar surface in combination with a dedicated heat and mass transfer model [5] to simulate the migration of water into and within the subsurface. A detailed model description and discussion of subsurface ice migration dynamics is published elsewhere [6]. Here we focus on results related to the short-term capture and release of water as a contributor to the overall lunar water cycle.

For this study we simulated three selected locations around a latitude of 59 deg South in the Clavius region of the Moon (Figure 1), where recent direct observations of water in illuminated areas have been reported [7]. The selected sites C1 and C2 are located at opposite sides of Clavius D crater and receive drastically different solar radiation. The maximum total heat input is 140 W/m² for C1 and 1034 W/m² for C2. Site C3 is located on the floor of Clavius crater and receives moderate solar radiation due to the high solar incidence angle, with a maximum total heat input of 612 W/m². Simulation of external heat fluxes takes into account direct solar, albedo and infrared radiation, including scattering and shadowing due to local topography.

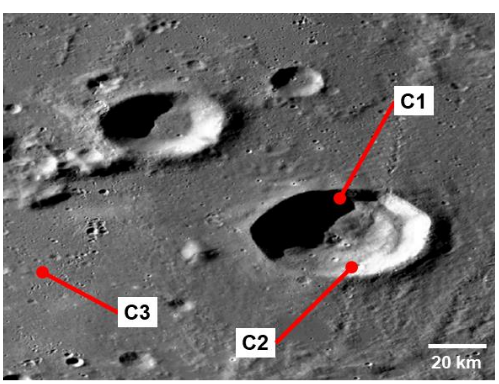

Figure 1: Investigated locations in the Clavius region. Image of LROC WAC mosaic taken from Lunar QuickMap.

Table 1: Coordinates and calculated surface temperatures at the investigated locations

Site	Latitude [deg]	Longitude [deg]	Surface temperature [K]		
			Min.	Mean	Max.
C1	-58.4688	-12.4375	55	115	225
C2	-59.1563	-12.3125	71	191	372
C3	-59.2188	-15.4375	65	174	326

Model description: The lunar subsurface model was implemented in COMSOL Multiphysics with a one-dimensional high resolution simulation of the first meter depth. Heat and mass transfer in the model are calculated based on the formulations described in previous work [5], which were optimized for larger soil volumes and timescales for this purpose. The model takes into account depth-, pressure- and temperature-dependent soil properties for heat and mass transfer and the water sorption kinetics at grain level.

As a boundary condition we assumed a constant supply of water onto the lunar surface at a rate of 10^{-15} kg/(m²·s), or $5.55 \cdot 10^{-14}$ mol/(m²·s). This order of magnitude is similar to estimates from previous work and includes the water flux from external sources and the in-situ production or release of water through molecular interactions on the surface [8,9].

The model simulation covers a duration of 300 lunations, or 25 lunar years, to evaluate long-term migration of water into the lunar subsurface. However, the time steps are small enough to resolve transient diurnal effects.

Daytime water release: To assess the quantity of water released during lunar day we calculated the flux of water molecules leaving the surface towards space and integrated it over the illuminate periods of the day, when direct solar and albedo radiation is zero. Figure 2 shows the results of integrated daytime fluxes as a histogram distribution.

Fluxes vary strongly over the investigated time due to the seasonally changing heat input and associated temperatures at the surface (Table 1). Because of the dynamic thermal conditions in the subsurface the thresholds for desorption/adsorption, as well as the gas diffusivity are constantly changing, leading to a rather widespread distribution of the flux intensities for site C2, the site with highest heat input. Average flux values however are on the order of 10^{-8} mol/m² for all three sites. A lower heat input at the surface tends to enable more effective water storage during night and thus a higher possible release during day, as the slightly shifted flux distribution the case for sites C1 and C3 show.

A significant water release on the order of >1µg/m² occurs during a fraction of 12%, 4% and 10% of the days in the investigated period for sites C1, C2 and C3 respectively.

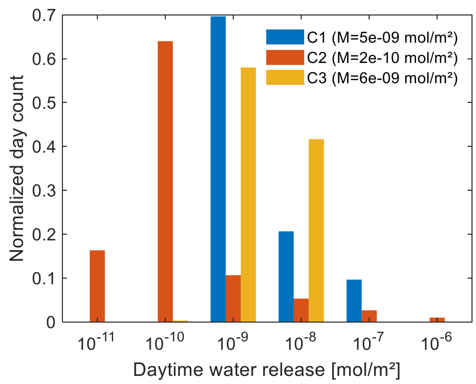

Figure 2: Histogram for the amount of water released to the exosphere at sites C1-3 during the lunar day. Median values are provided in the legend.

Conclusions: Recent remote sensing observations in the infrared wavelength range estimate that quantities of several hundred ppm of water may be released in sunlit areas [7,10]. Assuming that these measurements penetrate the first tens of micrometers of the lunar surface, the sampled soil mass per unit area is equivalent to 10-100 g/m². As shown above the daytime water release calculated with our model yields quantities >1 µg/m² in up to 12% of the lunar days in the investigated period of 25 years. In relation to the soil volume sampled by infrared spectroscopy this would be equal to several tens to hundred ppb. Although this is too low to solely explain the aforementioned observations, it should in principle be possible to observe such released water traces on the lunar surface even in illuminated areas. Also, as fluxes mainly occur shortly after local sunrise, the temporarily measurable quantities can be considered higher.

Our model results shows that trapping of water is possible even at locations with relatively high surface temperatures, as long as the night temperatures are low enough for long enough periods to allow adsorption. While temporarily captured water will not lead to larger accumulation of subsurface ice, it can nonetheless be considered one potential contributor to the lunar water cycle. For instance, this temporary storage mechanism could act as an important buffer for global water migration phenomena over larger distances.

A second relevant mechanism that could lead to observations of water signatures in illuminated areas is the release of shallow ice deposits via impacts. As we show in related work [6] such impacts would only have to disrupt the first upper centimeters of the surface to expose ice that has accumulated therein over larger timescales.

References: [1] Schorghofer, N. and Aharonson, O. (2014). *Astroph. Journal*, 788(2). [2] Schorghofer, N. and Taylor, G. J. (2007). *JGR*, 112(E2), E02010. [3] Schorghofer, N. and Williams, J.-P. (2020). *Planet. Sci. Journal*, 1(3), 54. [4] King, O. et al. (2020). *PSS*, 182, 104790. [5] Reiss, P. (2018). *Icarus*, 306, 1–15. [6] Reiss, P. et al (2021). *JGR*, under review. [7] Honniball, C. I. et al (2020). *Nat. Astron*. [8] Hayne, P. O. et al. (2015). *Icarus*, 255, 58–69. [9] Benna, M. et al. (2019). *Nat. Geosci.*, 12(5), 333–338. [10] Pieters, C. et al. (2009). *Science*, 326(5952), 568–572.