

TIME-OF-DAY-DEPENDENT BEHAVIOR OF LUNAR SURFICIAL HYDROXYL ON A ROUGH REGOLITH SURFACE. C. Wöhler¹, K. Wohlfarth¹, A. A. Berezhnoy² ¹Image Analysis Group, TU Dortmund University, Otto-Hahn-Str. 4, 44227 Dortmund, Germany (christian.woehler@tu-dortmund.de); ²Sternberg Astronomical Institute, Moscow State University, 119234 Moscow, Russia.

Introduction: On the surface of the Moon, hydroxyl (OH) and/or water (H₂O) molecules were detected based on the spectral absorption band near 3 μm in 2009 [1-3]. Some studies found a dependence of the strength of this absorption band on latitude [1, 3, 4] and time of day [3-6]. For further details, see the recent review of [7].

An overview of models of lunar surficial H, H₂, OH and H₂O is given in [7]. Among the fundamental physical processes governing the behavior of H and OH on regolith surfaces are the implantation of solar wind protons (H) followed by reactions with O atoms from the regolith as a source process and evaporation as a sink process [8]. A numerical treatment of these processes was introduced for H atoms in [9]. This framework was extended in [10] to surficial OH, where delivery of OH by micrometeoroids was included as an additional source and OH photolysis as an additional sink process. For typical settings of the physical model parameters, micrometeoroid-delivered OH turned out to be negligible against solar wind induced OH in [10].

The roughness of a regolith surface has a strong influence on its thermal regime [11]. Small cold traps exist in a rough regolith surface already at moderate latitudes [12]. In this study, we will thus apply the OH model of [10] to an artificial but realistic rough regolith surface and show first simulation results.

Rough-surface OH model: The OH model in [10] is a continuity equation formalism for modeling the time-of-day-dependent behavior of surficial OH under the assumption of a smooth surface. OH is formed by reactions between solar wind protons and O atoms from the surface material, and is removed by diffusion/evaporation and photolysis. The diffusion of OH obeys an Arrhenius law and thus depends exponentially on the surface temperature. The photolysis time is set to the constant gas phase value of 5×10^4 s [13]. The variable OH component is complemented by a more strongly bound OH component that is stable against diffusion and photolysis [10]. We applied this model to the individual facets of a simulated fractal rough surface that is constrained by in-situ observations of the lunar regolith [14, 15]. The spectrally detectable 3-μm band depth is computed by a weighted mean of the facet-specific OH column densities, with the corresponding reflectances as weights. The physical parameters of the model are described in detail in [10].

Thermal model: The artificial rough surface [14] is smoothed by a low-pass filter with a cut-off frequency

corresponding to the spatial scale of ~5 mm at which the transition between isothermal and isolating behavior occurs [10, 11]. We assume thermal equilibrium, so that the temperature of each surface facet, as given by the Stefan-Boltzmann law, depends on the facet-specific incidence angle and the directional-hemispherical albedo [16]. A raytracing routine is used to compute the shadowing of the incident sunlight and the self-heating between facets inclined towards each other.

Results: The rough-surface OH model is able to reproduce the basic characteristics of Moon Mineralogy Mapper (M³) [1] highland observations [4] (Fig. 1). The OH distribution across the surface is strongly non-uniform (Fig. 2), with the highest OH column densities occurring in surface parts of at most a few square centimeters area, that are illuminated but only under large incidence angles. At 45° latitude and beyond, these small-scale accumulations of OH persist throughout the lunar day. The mean OH column density increases with latitude, similar to the OH column density on a smooth surface (Fig. 3). The surface temperature shows strong local variations that increase with latitude (Fig. 4). At 75° latitude, the mean OH column density is constant, so that the observed variations of the relative 3-μm band depth (Fig. 1) are due to the relative contributions of bright and dark facets changing with time of day. The local variations of the OH column density are anti-correlated with surface temperature, as revealed by a comparison between Figs. 4 and 5.

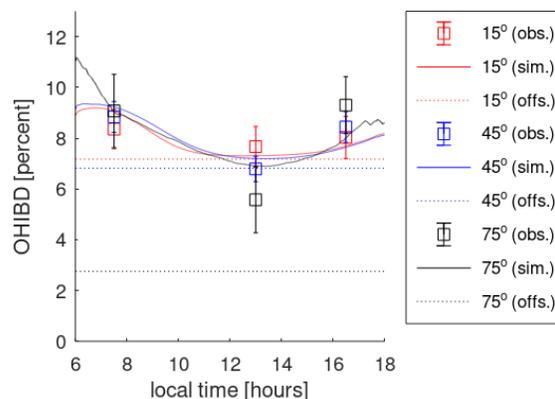


Fig. 1: Observed vs. simulated time-of-day-dependent behavior of the relative 3-μm band depth (OHIBD) for highland areas of $2^\circ \times 2^\circ$ size at 257.5° longitude and $\pm 15^\circ$, $\pm 45^\circ$ and $\pm 75^\circ$ latitude. Thermal correction was performed with 9° RMS roughness angle [4]. Error bars are ± 1 standard deviation. Dotted horizontal lines indicate the fitted strongly bound OH component. The diffusion time of H atoms is $10^{-6} \text{ s} \times \exp(0.5 \text{ eV}/(k T))$.

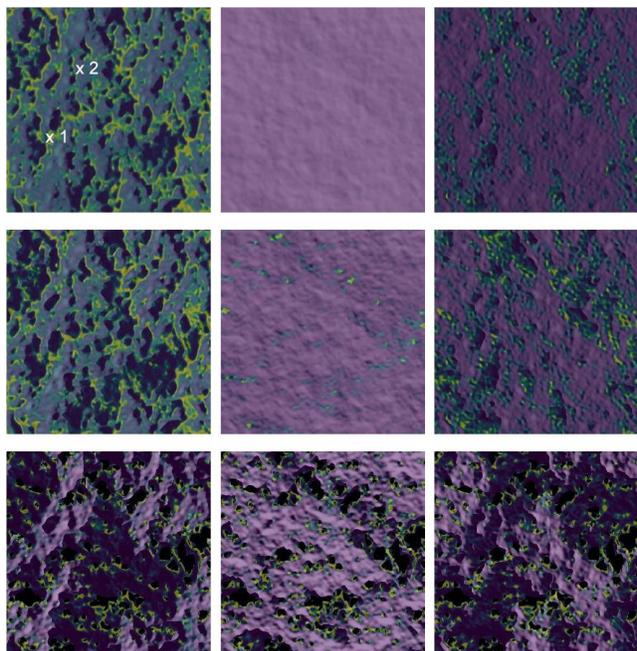


Fig. 2: Simulated column density of solar wind induced OH in m^{-2} , overlaid on the surface reflectance, at local times of 07:30 (left), 13:00 (middle) and 16:30 (right) for latitudes of 15° (top), 45° (middle) and 75° (bottom). Surface area is $300 \times 300 \text{ mm}^2$. Location 1 has a high and location 2 a low OH column density.

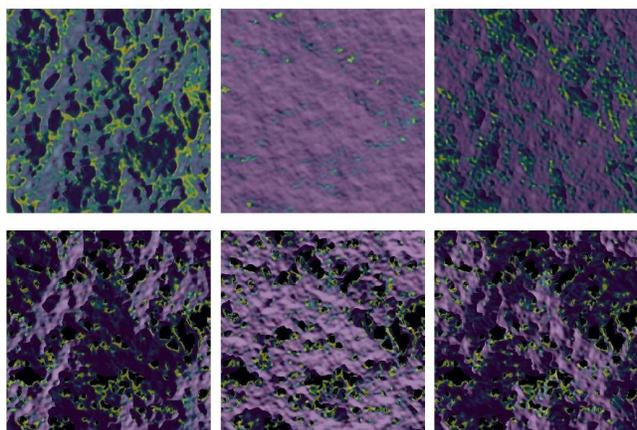


Fig. 3: Simulated column density of solar wind induced OH (mean of rough surface, smooth surface) for 15° , 45° and 75° latitude.

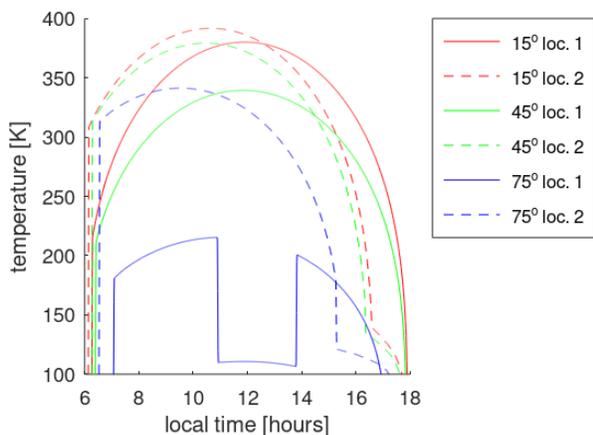
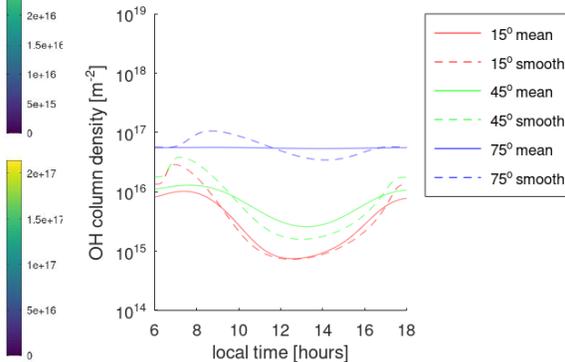


Fig. 4: Simulated surface temperature at locations 1 and 2 at 15° , 45° and 75° latitude.

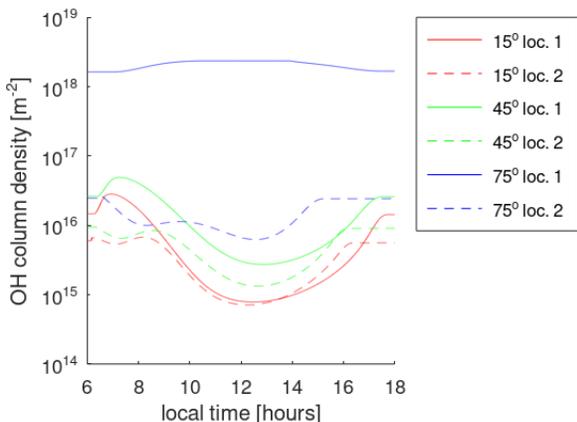


Fig. 5: Simulated column density of solar wind induced OH at locations 1 and 2 for 15° , 45° and 75° latitude.

Conclusion: We have applied the physical model of lunar surficial OH of [10] to an artificial, realistic rough regolith surface. We found that the OH column density exhibits significant variations across the surface, which become as strong as two orders of magnitude at 75° latitude. Our model is able to reproduce the variations of the $3\text{-}\mu\text{m}$ band depth observed in M³ data. Already at moderate latitudes, small-scale OH accumulations persist during the complete lunar day in surface areas that receive solar wind protons but are illuminated only under high incidence angles, resulting in a relatively low surface temperature. These results indicate that the surface roughness is of critical importance for an understanding of the observed behavior of lunar surficial OH.

References: [1] Pieters, C. M. et al. (2009) *Science* 326 (5952), 568-572. [2] Clark, R. N. et al. (2009) *Science* 326 (5952), 562-564. [3] Sunshine, J. M. et al. (2009) *Science* 326 (5952), 565-568. [4] Wöhler, C. et al. (2017) *Sci. Adv.* 3(9), e1701286; data available at <https://doi.org/10.5281/zenodo.5773293>. [5] McCord, T. B. et al. (2011) *JGR* 116, E00G05. [6] Honniball, C. I. (2020) *JGR* 125(9), e06484. [7] Schörghofer, N. et al. (2021) *Space Sci. Rev.* 217(6), 74. [8] Starukhina, L. (2001) *JGR* 106(E7), 14701-14710. [9] Farrell, W. M. et al. (2015) *Icarus* 255, 116-126. [10] Grumpe, A. et al. (2019) *Icarus* 321, 486-507. [11] Bandfield, J. L. et al. (2015) *Icarus* 248, 357-372. [12] Davidsson, B. J. R. and Hosseini, S. (2021) *MNRAS* 506(3), 3421-3429. [13] Huebner, W. F. and Mukherjee, J. (2015) *PSS* 106, 11-45. [14] Wohlfarth, K. et al. (2021) *LPSC LII*, abstract #1241. [15] Helfenstein, P. and Shepard, M. K. (1999) *Icarus* 141(1), 107-131. [16] Shkuratov, Y. et al. (2011) *PSS* 59(13), 1326-1371.