Bulk Insolation Models as Predictors for Locations for High Lunar Hydrogen Concentrations. T.P. McClanahan[1], I.G. Mitrofanov[2], W.V Boynton[3], G. Chin[1], R.D. Starr[4], L.G. Evans[5], A. Sanin[2], T. Livengood[1,6], R. Sagdeev[6], G. Milikh[6], Astrochemistry Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, (timothy.p.mcclanahan@nasa.gov), [2]Institute for Space Research, RAS, Moscow 117997, Russia, [3]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson AZ, [4]Catholic Univ. of America, Washington DC, [5]Computer Sciences Corporation, Lanham MD 20706, [6]Univ. of Maryland, College Park.

Introduction: In this study we consider the bulk effects of surface illumination on topography (insolation) and the possible thermodynamic effects on the Moon's hydrogen budget. Insolation is important as one of the dominant loss processes governing distributions of hydrogen volatiles on the Earth, Mars and most recently Mercury [1-3]. We evaluated three types of high latitude > 65°, illumination models that were derived from the Lunar Observing Laser Altimetry (LOLA) digital elevation models (DEM)'s [4]. These models reflect varying accounts of solar flux interactions with the Moon's near-surface. We correlate these models with orbital collimated epithermal neutron measurements made by the Lunar Exploration Neutron Detector (LEND) [5]. LEND's measurements derive the Moon's spatial distributions of hydrogen concentration. To perform this analysis we transformed the topographic model into an insolation model described by two variables as each pixels 1) slope and 2) slope angular orientation with respect to the pole. We then decomposed the illumination models and epithermal maps as a function of the insolation model and correlate the datasets.

In this process we effectively linearized the insolation continuum between poleward and equatorward facing slopes where insolation increases from left to right in the map. Our results indicate the same approach applied to LEND maps yields a similar correlated pattern. From this result we suggest insolation has similar effects on the hydrogen budget as it does near the poles of Earth, Mars and Mercury.

Background: For more than a decade the Lunar Prospector Neutron Spectrometer's (LPNS) measurements of the broad suppression of epithermal neutron emission rates at the Moon's poles were taken as evidence for polar accumulations of hydrogen [6]. This result was consistent with the hypothesis that accumulations of hydrogen bearing volatiles might be concentrated in high latitude permanently shadowed craters [7]. However, three years of accumulated observations from the Lunar Exploration Neutrond Detector (LEND) onboard the Lunar Reconnaissance Orbiter (LRO) indicate only a few of the permanently shadowed regions (PSR)'s maintain significantly enhanced concentrations of hydrogen [8]. Indeed, the total area and loci of suppressed epithermal neutron rates near permanent shadow regions does not appear to be an adequate explanation for the much broader polar suppression of epithermal neutron rates called an Extended Polar Suppression of Epithermal Neutron (EPSEN) [9].

In an effort to better understand the EPSEN observations we consider insolation and the correlation between increased illumination, thermal conditions and degree of hydrogen mobilization. Local illumination conditions are an ephemeral process, modulated heavily by diurnal, seasonal, latitude and topographic variation. Its effect on the hydrogen budget is critically dependent on the dynamics of hydrogen accumulation and other loss processes which are presently not well understood [10]. Different solar flux models have been developed to account for average and maximum surface exposure and provide possible insite into the near-surface hydrogen budget (~10's cm). These models include: 1) Average illumination: count of the number of times each pixel is illuminated 2) Average flux: weighted average of solar incidence angles 3) Maximum Flux observed [11]. The models were derived using the ephemeris of several 18.6 year lunar precessions.

Our postulate is that insolation is one of the dominant factors in the EPSEN observation. The insolation model generates a unique linearized pattern (map) used to correlate the solar flux models and epithermal maps. This evaluation identifies the best predictors of epithermal rates and inferred high hydrogen locations.

Methods: LEND maps were prepared using primary and extended mapping mission derived LEND collimated sensor (CSETN) data (DLD), Sept 15, 2009 to October 2012. North and South polar maps +/-65° to poles are produced using a 2800x2800 pixel, 0.4 km resolution map. LEND integrates its four collimated sensors at 1-Hz rate and we used a 2-D 25-km uniform area mapping disk to perform mapping.

Illumination models were derived using two polar (N,S) LOLA, 0.4 km resolution digital elevation models (DEM) selected from the LOLA Planetary Data System release (Dec 15, 2011) files: ldem_45(s,n)_400m.img, $\mathbf{m}$. We calculate the topography directional gradients and slope $\mathbf{s}$ by convolving the topography with a 1st derivative Gaussian kernel. Using the image position of each pole we calculate each pixels slope orientation **Φ** [7]. All maps can then be described by the insolation model [**s**, **Φ**].

Results: Figures 1 A, B illustrate LEND's collimated North and South epithermal count rate maps, ±65° to poles, rebinned using the 2-D insolation functional with slope (0 to 15°) and slope orientation (0 = poleward facing, 180 = equatorward facing). For both poles, high-poleward facing slopes (left) have lower epithermal rates (i.e higher hydrogen) than equatorward slopes. Map count rates range between [4.841, 4.863] and [4.856, 4.880] cps. Importantly, north and south maps appear to reflect different equatorward effects as illustrated in the correlations in Figs. 2A, B. In Figs 1C, D the coregistered LOLA illumination maps are similarly reaveraged indicating lowest illumination in high, poleward facing slopes. (Avg and Max Flux examples are not depicted).

Figures 2A, B illustrate the Pearson correlation of the collimated epithermal maps (CSETN) to the three solar flux models. 2A, North correlations indicate the three solar flux models are similarly correlated [0.72, 0.72, 0.67]. However, for South correlations the illumination model is clearly better correlated [0.88, 0.52, 0.41]. In Figure 2B, we reran the 1C analysis after removing all pixels classified as having permanent shadow, i.e with Illumination > 0%. As a result, only small decreases in correlation to the insolation function were noted. This likely indicates epithermal rates and illumination conditions >0% are also continuously correlated via insolation.

Conclusions: Evidence strongly suggests, that as on Earth, Mars and Mercury, insolation at the Moon's poles is an important factor in locally modulating hydrogen concentrations. In cratered topography, the highest concentrations may be found on poleward facing vs. equivalent equatorward slopes. Further, results confirm the extended polar suppression of epithermal neutrons (EPSEN) is only weakly related to permanent shadow and likely best correlated to the low end of the insolation continuum. However, some localized high-latitude variations in hydrogen concentration exist that are not explained via insolation. These will be further evaluated in future study.

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