DIURNAL AND LATITUDE DEPENDENCE OF MOLECULAR WATER ON THE LUNAR SURFACE: RESULTS FROM 6 MICRON EMISSION MEASUREMENTS BY SOFIA. P. G. Lucey, 1 A. J. Thorpe, 2 C. I. Honniball, 3 W. T. Reach, 4 A. Arredondo, 5 M. J. Poston, 6 E. Malaret 6 1 University of Hawaii at Manoa, Honolulu HI, USA, lucey@hawaii.edu, 2 Universities Space Research Association, Columbia, MD, USA, 3 University of Maryland, College Park, MD, USA, 4 Space Science Institute, Boulder, CO, USA, 5 Southwest Research Institute, San Antonio, TX, USA, 6 Applied Coherent Technology, Inc. Herndon VA USA

Introduction: The distribution, transport and sequestration of molecular water on the Moon is important for understanding volatile transport on airless bodies, as well as the sustainability of ice deposits at the lunar poles. LADEE upper limits on water at the equatorial exosphere limit the effectiveness of ballistic migration as a transport mechanism [1,2]. However, if even a portion of the temperature variable lunar 3μm band is due to variation in surface water, this implies very large masses of water exchanging between the surface and exosphere [3,4]. However, the 3μm band can be due exclusively to hydroxyl, thus it is important to unambiguously measure any variation in surface water abundance.

Measurements of surface water using the H-O-H bend feature near 6 μm unambiguously detects molecular water, unlike UV or near-IR spectroscopy. Surface water was detected at high southern latitudes [5], and variations in this feature attributed to temperature have also been reported [6], using spectra obtained from the FORCAST spectrometer on the Stratospheric Observatory For Infrared Astronomy (SOFIA). Here we report results from a major portion of the entire SOFIA lunar data set seeking systematic variations in abundance and distribution of water to shed light on its behavior.

Data: FORCAST provided long slit spectroscopy covering 5-8 μm with a spectral resolution of R=200. SOFIA data are reduced to spectral radiance after [7], and 6 μm data are fit using a Gaussian to derive peak heights, that are subsequently converted into μg/g of molecular water. SOFIA lunar data distribution is shown in Fig. 1. The total data set comprise 229,578 spectra that are widely but not randomly distributed in surface temperature, photometric geometry, latitude, longitude and lunar time of day.

Results: the several km scale of SOFIA data, the lunar 6 μm emission peak is weak, with maximum peak heights near 4%; the mode of the distribution is near 1.5% (Fig. 2). Using the calibration of [5], a peak height of 1% corresponds to about 150 μg/g of molecular water.

Figure 1. Spatial distribution of data from SOFIA used in this work. Red indicates data obtained within the maria, and blue are data in the highlands. The highland-mare border is in black.

Figure 2. Distribution of peak heights over the data set.

Three parameters dominate variation in the intensity of the 6 μm emission peak: latitude, temperature and emission angle. There is a weak difference in abundance vs. temperature between the highlands and maria. We find no dependence on phase angle, solar wind intensity or fluence. Incidence angle cannot be separated from temperature as much of the lunar surface is in radiative equilibrium with solar irradiance that is dominated by incidence angle. To isolate the effect of the three dominant parameters, for each we constrain the range of values for the other two, and also select data covering the maximum range of the data. Constraining temperature and emission angle, we find strong variation in peak intensity with latitude, roughly following an inverse cosine of latitude [Fig. 3]. Similarly constraining latitude and emission angle, we find a strong
approximately linear inverse correlation of peak intensity with temperature, with a rate of change of about 2 µg/g per kelvin [Fig. 4]. Emission angle, not shown, has a similar effect.

![Figure 3. Water concentration with latitude. Temperature is constrained to 325 to 333K and emission angle confined to 40-50 degrees](image3)

![Figure 4. Water concentration with temperature. Latitude is constrained to 35-45N and emission angle confined to 40-50 degrees](image4)

Discussion: Our results suggest molecular water features two populations. One is a fixed latitude-dependent, likely axially symmetric distribution of persistent water not affected by temperature. The second is dependent on temperature and time of day, but also latitude as there is little variation in abundance with temperature near the equator (not shown).

Persistent latitude dependence. The fixed population is consistent with the proposal by [5] that water is sequestered in impact glass. The distribution may be related to the suggestion by [8] that hydroxyl increases with latitude due to production of molecular water by associative desorption at low latitudes and accumulation at high latitudes by dissociative adsorption. In our interpretation, some of this hydroxyl is converted to water in micrometeorite impacts [9] and stored in impact glasses.

Temperature dependence. Variation in surface abundance with temperature nominally supports transport of water by ballistic migration. However, the abundance and variation in abundance appears to imply far too much water in the exosphere. A simple equilibrium calibration that links the residence time on the surface to the time in flight for reasonable lunar temperatures and the mass of water in the optical surface yields many orders of magnitude more water molecules per unit volume than LADEE limits. Similarly, the supply to the exosphere implied by the decline in surface water during the day provides a similar order-of-magnitude problem.

Conclusions: A 6 µm emission feature is ubiquitous on the Moon, though weak with an average peak height of about 2%; our measurements enable establishing sensitivity requirements for future 6 µm spectroscopy of the Moon. We find a persistent latitude dependent component we attribute to water trapped in impact glass. We also find a temperature dependent component with a subordinate latitude dependence that shows that the abundance of water in the optical surface varies with time of day. The mass of exchangeable water if attributed to ballistic migration of water appears to be in conflict with LADEE upper limits on background water abundances of < 3/cc.