ESTIMATION OF LUNAR SURFACE TEMPERATURES: A NUMERICAL MODEL.

K. Bauch[1], H. Hiesinger[1], J. Helbert[2]. [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany. [2]DLR-Inst. für Planetenforschung, Rutherfordstr. 2, 12489 Berlin. Karin.Bauch@uni-muenster.de

Introduction: About 40 years after the Apollo and other lunar missions, several nations return to the Moon. Indian, Chinese, Japanese and American missions are already in orbit or will soon be launched, and the possibility of a “Made in Germany” mission (Lunar Exploration Orbiter – LEO) looms on the horizon. In preparation of this mission, which will include a thermal infrared spectrometer (SERTIS - SElenological Radiometer and Thermal infrared Imaging Spectrometer), accurate temperature maps of the lunar surface are required [1]. Because the orbiter will be imaging the Moon’s surface at different times of the lunar day, an accurate estimation of the thermal variations of the surface with time is necessary to optimize signal-to-noise ratios and define optimal measurement areas.

In this study we present new temperature estimates for sunrise, noontime and sunset. This work provides new and updated research on the temperature variations of the lunar surface, by taking into account the surface and subsurface bulk thermophysical properties, namely their albedo, bulk density, heat capacity, thermal conductivity and emissivity. These properties have been derived from previous spacecraft-based observations, in-situ measurements and returned samples [2, 4-10]. Topographic effects also influence the temperatures as sloping surfaces change the angle of solar inclination and elevated areas expect sunlight earlier and over a longer period. Our work expands on the work of Lawson et al. [2] who calculated global brightness temperatures of subsolar points from the instantaneous energy balance equation assuming the Moon to be a spherical object [2].

Numerical model: In order to determine surface and subsurface temperatures, the one-dimensional heat conduction equation

$$\rho(z)C(T)\frac{\partial T(z,t)}{\partial t} = \frac{\partial}{\partial z}\left[k(z,T)\frac{\partial T(z,t)}{\partial z}\right] \quad (1)$$

has to be solved [e.g. 3,4]. ρ(z) denotes the depth-dependent bulk density, C(T) the heat capacity and k(z,T) the thermal conductivity, which is dependent on both, depth and temperature. The thermophysical parameters can be summarized to a thermal inertia:

$$I = \sqrt{k\rho C} \quad (2)$$

representing the ability of the surface to adapt to temperature changes [3-6]. Equation (1) is solved with the surface boundary condition

$$\frac{S_0}{R^2}\cos(i)\,(1-A) + k\frac{\partial T}{\partial z}\Big|_{z=0} = \varepsilon\sigma T_{z=0}^4 \quad (3)$$

The first term is an insolation function, which includes the solar flux (S_0) at 1 AU, the orbital radius (R) and the surface albedo (A). Ephemeris data containing the distance, azimuth and elevation are determined with the Jet Propulsion Laboratory Horizons software and updated in each time step. Solar inclination (i) is calculated from this data. The second term represents the subsurface conditions. The bottom layer boundary condition is given by

$$q = -k\frac{\partial T}{\partial z}\Big|_{z=zb} \quad (4)$$

q is the heat flow at the bottom, which is assumed to be constant. Therefore the bottom layer has to be deeper than the intrusion depth of diurnal or annual periodic temperature variations in order to ensure a constant heat flux from below. Heat flow values are given by [8]. The partial differential equation is converted to an ordinary differential equation using a spatial discretization. Mesh points are spaced with an increment of 5mm within the first 5cm, because temperature changes rapidly near the surface. An increment of 2cm is chosen for depth nodes between 6cm and 50cm and depths deeper than 50cm have increments of 10cm.

The heat transport equation is solved for a resolution of about 0.4°, which is better by a factor of 2 compared to the Clementine measurement and temperature modeling described in [2].

Surface daytime temperatures are mainly controlled by their surface albedo and angle of incidence. On the other hand nighttime temperatures are affected by changes in the thermal inertia. Topographic effects are expected to cause earlier or later sunrises and therefore high-standing areas receive sunlight for longer time, while sloping surfaces lead to a time displacement of the temperature cycle. For our model, some simplifications were necessary. In order to determine the solar influx, the Moon is assumed to be spherical. As there are only few landing sites from which soil properties were determined, the subsurface conditions are considered as homogeneous over the whole Moon.

Thermophysical properties: The surface of the Moon is covered by a layer of fine grained material, the so-called regolith. The bulk density has been measured for several samples brought back from the Apollo missions. For this study a constant bulk density of 1300kg m^{-3} is used [9,10]. Heat capacity varies strongly with temperature. In the temperature range between 80K and 390K at the surface, it varies by a factor of 4. A constant value for the heat capacity cannot be used for the determination of evening and nighttime temperatures, therefore it is expressed by a third-degree polynomial as proposed by [11]. In the lunar regolith heat is transferred by two different modes. First by solid conduction through particles and second by radiation [5]. Thus thermal conductivity can be expressed as a combination of a conductive and radiative component [3-5].

Results: Fig. 1 shows the temperature variations at the North and South Poles in comparison to the equator for a period of 400 days, assuming the Moon to be spherical. At the equator surface temperatures show amplitudes of the order of 250K, while the amplitude at the poles is around 100K. Maximum polar temperatures are found to be nearly 170K, while minimum temperatures are around 60K.

The maximum surface temperatures for latitudes between 75°N and 75°S are shown in fig. 2. Surface temperatures vary between 240K at high latitudes and 390K at the mare regions near the equator. Temperatures for latitudes higher than 75° have been excluded because topographic effects intensely influence the temperatures. Nighttime temperatures are around 100K, which is in good agreement to the Apollo 15 and 17 temperature measurements described by [7].

In order to determine the albedo influence on surface temperatures a map that shows the difference between albedo influenced temperatures minus temperatures of a uniform surface has been created. Maximum temperatures differ about ±15K between mare regions and highlands.

Topographic effects due to sloping surfaces have also been investigated. Surfaces having a slope of 20° reach their maximum temperatures about 2 days before or after a plane surface, depending on their orientation. Temperature differences of 150K have been found between sloping (20°) and non-sloping surfaces shortly after sunrise.

References: [1] Jaumann, R. et al. (2008) *LPSC XXXIX,* Abstract #1253; [2] Lawson, S.L. et al. (2000) *JGR 105, E2,* 4273-4290; [3] Linsky, J.L. (1966) *Icarus 5,* 606-634; [4] Keihm, S.J. et al. (1973) *Earth Plan. Sci. Let. 19*, 337-351; [5] Cremers and Hsia (1974) *Proc. 5th Lunar Conf., Suppl. 5, Geochim. et Cosmochim. Acta, Vol. 3*, 2703-2708; [6] Robie, R. et al. (1970) *Proc. Ap. 11 Lun. Sci. Conf., Vol. 3*, 2361-2367; [7] Keihm, S.J. and Langseth, M.G. (1973) *Proc. Lunar Sci. Conf. 4th*, 2503-2513; [8] Langseth, M.G. et al. (1976) *Proc. Lunar Sci. Conf. 7th*, 3143-3171; [9] Racca, G.D. (1995) *Planet. Space Sci., Vol 43, No. 6*, 835-842; [10] Vasavada, A.R. et al. (1999) *Icarus 141,* 179-193; [11] Robie, R.A. et al. (1970) *Science 167, No. 3918*, 749-750;

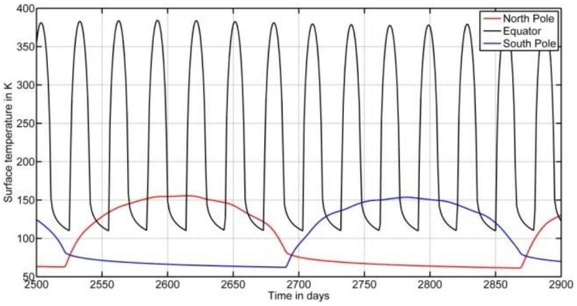

Figure 1. Comparison of temperature variations between North and South Pole and the equator over a period of 400 days assuming the Moon to be spherical.

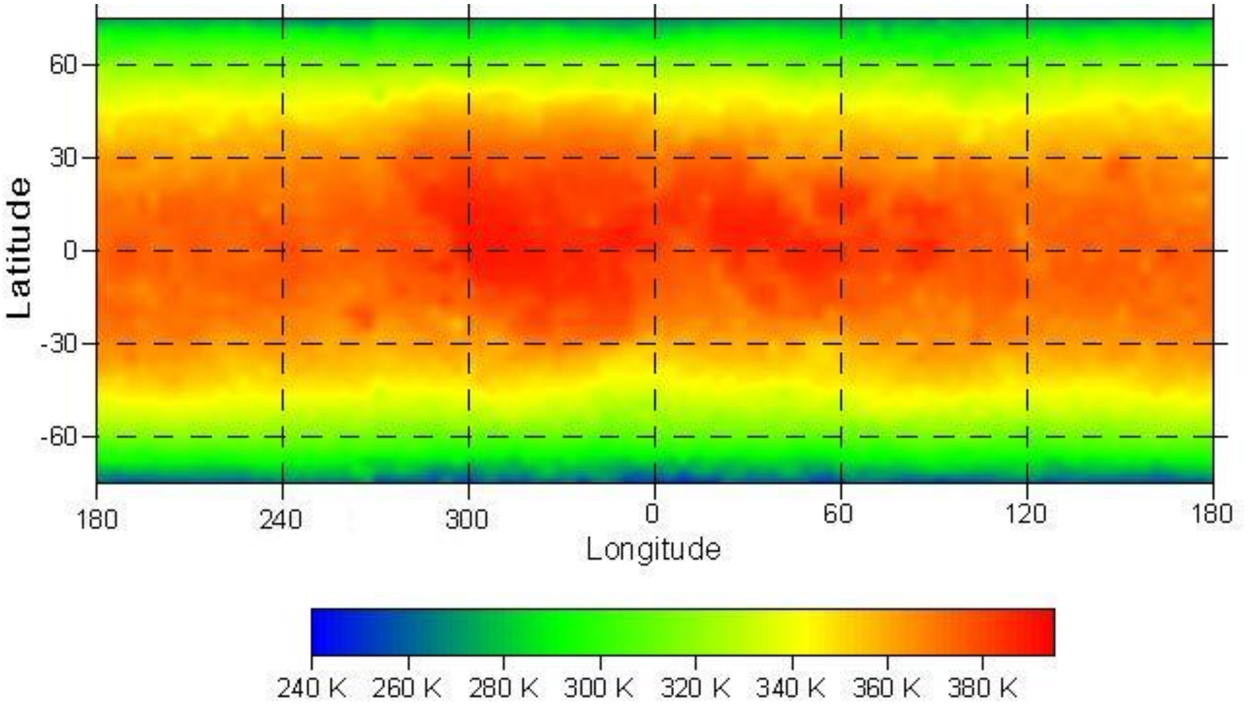

Figure 2. Global map of maximum surface temperatures with a resolution of 0.4 degrees.