A COMPREHENSIVE 3D THERMAL MODEL FOR AN INSIGHT INTO DIURNAL AND LATITUDE VARIABILITY OF LUNAR SUBSURFACE TEMPERATURES K. Durga Prasad, Vinai K. Rai and S.V.S. Murty, Physical Research Laboratory, Ahmedabad 380009, India (durgaprasad@prl.res.in)

Introduction: Systematic measurements of heat loss from lunar interior and its spatial variation are needed to estimate the net heat flow on the Moon. Thermal measurements of the Moon gained importance in light of recent results from various instruments onboard lunar missions such as LRO, GRAIL and Chandrayaan-1. Although heat flow measurements will be of top priority for future in situ geophysical exploration of the Moon, no such mission is in the offing at least for the next decade. At this point, the only way we can improve our current understanding about these aspects is through laboratory experiments and numerical simulations. Apollo Heat Flow Experiments have provided some knowledge about lunar thermal behavior, but restricted to only equatorial latitudes. Thermal behavior at mid and high latitudes is not at all known. It is well known that the subsurface temperatures of Moon are dictated by a number of parameters. We are addressing this problem through a comprehensive thermal model to understand the surface and near subsurface thermal behavior of the Moon.

Description of Model and parameters: It is a three dimensional finite element model capable of simulating variable layers, layer thickness and dimensions. Detailed description is given in [1]. The model is designed to account for complex geometry, different size, irregular meshing, parametric based variation in physics and boundary conditions. At present the model is validated to account for local to regional scale variations and flat surfaces. The model was designed and run for both single and two layers (considering top 2 cm as fluff). Parameterisation and boundary conditions

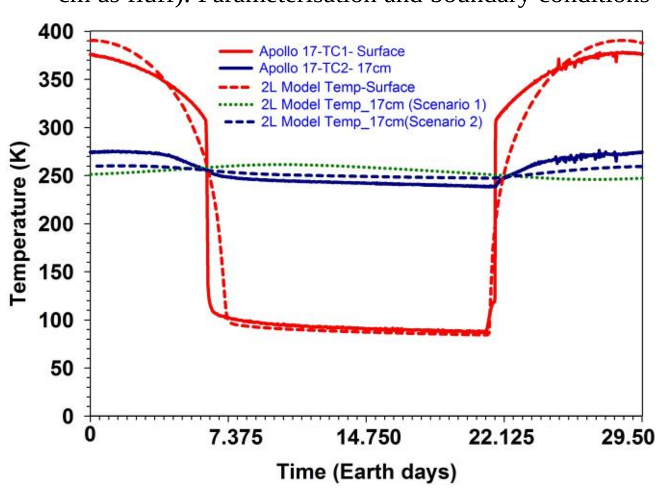

Figure 1: Comparison of Model derived surface and subsurface temperature with Apollo 17 in situ data.

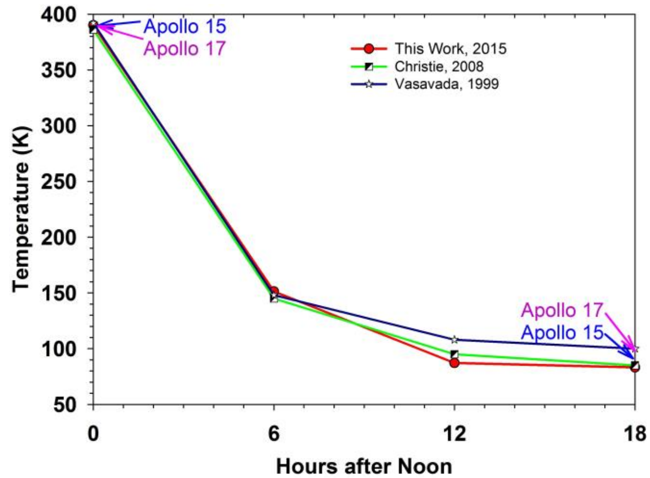

Figure 2: Model derived diurnal evolution of temperature - Comparison with Apollo data and earlier Models.

incorporated in the model are based on literature data and Apollo 17 Site (for ground truth). According to literature, the combined effect of temperature dependent thermal conductivity and Specific heat account for ~20-50% of the diurnal variation of thermal Inertia of lunar surface. Also to account for radiative and conduction components in porous media, temperature dependent thermal conductivity and specific heat was considered in the model[2]. The surface boundary heat condition was considered as a semi-sinusoid function with a peak flux of 1360.9 W/m^2 with a synodic period of 29.5 Earth days. The surface emissivity of the top layer was considered as 0.95.

Results and Discussion: Using the above model, we have carried out simulations for diurnal and annual cycles for all latitudes. The simulations were carried out for a block of plane surface of area 2m x 2m with a height of 1m. In the beginning of simulation, the initial value of temperature was considered to be 250K throughout. The model results have been validated against laboratory experiments[1], in-situ data and earlier models. Some of the results from these simulations are presented here.

Model validation with Apollo17 in situ data: Figure 1 shows a comparison of diurnal variation of surface and subsurface temperatures (at a depth of 17 cm) obtained from the model and Apollo 17 heat flow probe data. It can be clearly seen that the model derived diurnal variation in surface and subsurface temperatures are in good agreement with Apollo 17 in situ data. For a depth of 17 cm. two scenarios were considered for

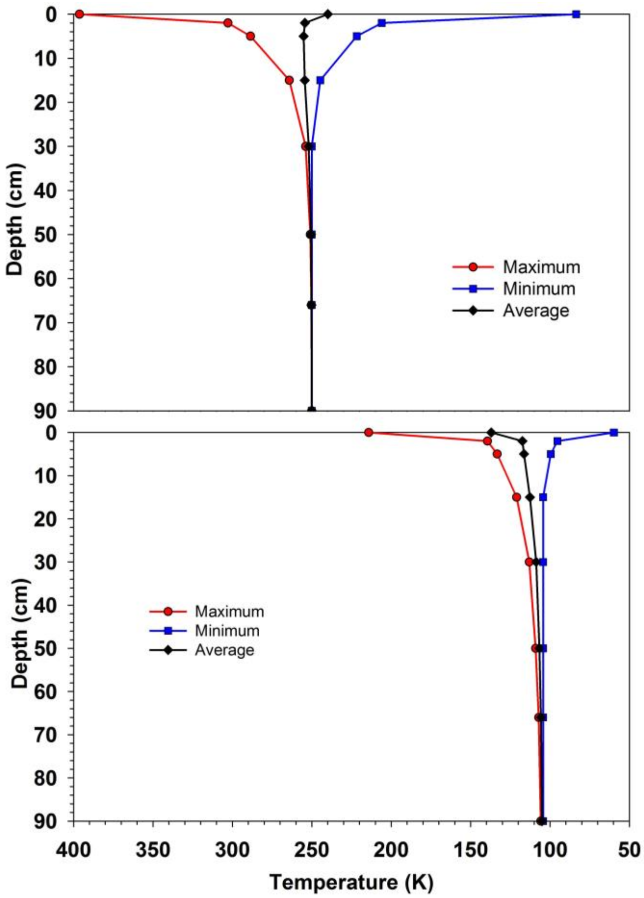

Figure 3: Subsurface Temperature and diurnal skin depth for equator and 85^o latitude

model simulations. The first scenario is a porous material and second scenario mimics Apollo 17 heat flow probe deployment, where the sensor at 17cm of Apollo heat flow probe is hanging at the centre of the bore stem and not in contact with regolith. This implies that the sensor is measuring the radiated heat within the bore stem. It is clearly seen that the model derived plot using second scenario better mimics (within model uncertainties) the Apollo in situ data at that depth. These results thus validate the credibility of the developed model to simulate the realistic conditions on the Moon. Figure 2 shows the comparison of model derived diurnal evolution of surface temperature with that of Apollo in situ data [3] and earlier models [4,5] and are found to be in good agreement.

Subsurface Temperatures and diurnal skin depth: Figure 3 shows the surface and subsurface temperatures as a function of depth for equator and high latitude. The results show that the high latitudes register a larger diurnal skin depth when compared to that of mid and low latitudes.

Latitude Variation of Surface and Subsurface Temperatures: Although some idea of latitude variation of surface temperatures is available from remote sensing observations, systematic data for subsurface temperatures for different latitudes is not available either from in-situ observations or by models. Using the present model, we have attempted to systematically derive subsurface temperatures for different latitudes of the Moon by using most appropriate parametrisation[6]. Lack of in situ data for subsurface temperatures at mid and high latitudes makes it difficult to define the initial boundary condition. To address this, we have used the formulation derived from ChangÉ-2 microwave radiometer [7]. Figure 4 shows the latitude variation of surface and subsurface temperatures. Purple curves in figure 4 are the latitude variations of temperatures for surface and a depth of around 1 metre derived from earlier 1-D model[4]. The two purple lines (dash and dot dash) at bottom correspond to earlier 1-D model runs considering single and two layers[4]. It can be seen that the results simulated by the present model are in good agreement with earlier model.

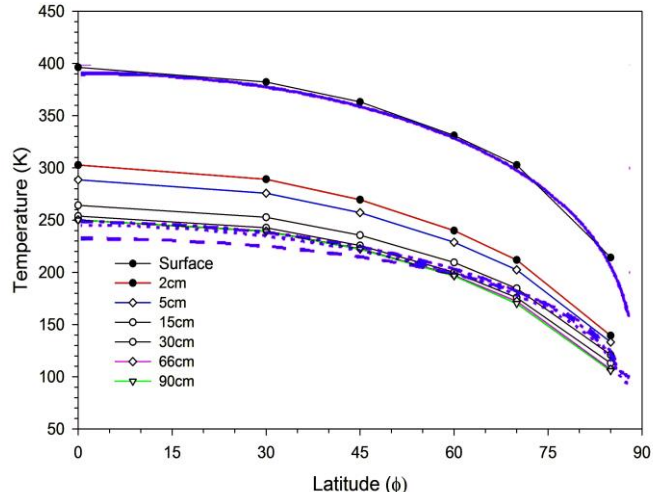

Figure 4: Latitudinal variability of subsurface temperatures

Summary and Future Work: A comprehensive 3D thermal model has been developed to understand the thermal behaviour of the near-surface regolith of the Moon. The model results have been validated against in situ data and earlier models. We could systematically estimate the subsurface temperatures at various latitudes. Our model results are in good agreement with Apollo in situ measurements, Diviner observations and earlier models. Further improvements of the model to incorporate local terrain effects (particularly for high latitudes) are in progress.

References:[1] Durga Prasad et al., (2015) 46th LPSC #1768.pdf [2] Cremers et al., (1971), Moon, 346-351 [3] Lauderdale and Eichelman (1974) NASA TM X-58131, 10.6-10.49 [4] Vasavada et al., (1999), Icarus 141, 179-193 [5] Christie et al., (2008) NASA TM-215300, 1-13 [6] Durga Prasad et al.,(2015) AOGS [7]Fa and Jin (2010) Icarus, 605-615