International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 18, Number 2 (2023), pp. 107-112

http://www.ripublication.com/ijaes.htm

One dimensional Energy Balance Model for Moon surface temperature for comparison with Chandrayan-3 measurements

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Abstract

Recently launched Chandrayan-3 by Indian Space Research Organisation (ISRO) has successfully landed a module Vikram and a rover Pragyan near south Pole region of Moon surface. Some instrument (ChaSTE) on Vikram has measured the surface temperature at the landing point (69.373 S, 32.319 E) . This measurement has been compared with some theoretical simulation of lunar surface temperatureat that point by energy balance model.

Energy Balance Model for Moon

To find out the global average surface temperature of Moon, a simple 0-dimensional energy balance model may be developed. To have an equilibrium temperature, the incoming solar energy, S absorbed at the surface will be balanced with the outgoing thermal emitted energy from the surface. For simplicity, if the albedo and emissivity of the Moon are considered to be 0.0 and 1.0 respectively, then

$$\pi r^2 S = б(4\pi r^2) {T_M}^4 \qquad \ldots (1)$$

where S is the solar constant for Moon, r is the radius of Moon, T_M is the Moon surface temperature and б is the Stefan-Boltzman constant (= 5.67 x 10^{-8} $Wm^{-2}K^{-4}$). Here it may be noted that the solar energy is received in area ofπr^2 , whereas the emitted area is $4\pi r^2$.

Solar constant at Moon is about 1400 W/m^2 ,when the Earth is at perihelion and about 1310 W/m^2 ,when the Earth is at aphelion (Kaczmarzyc et al. , 2018). Solving the above equation with these values, when the Earth is at perihelion, one can get that the global average surface temperature of the Moon will be about 280 K or 7 C.

One dimensional Model

If one looks at the Moon as one dimensional disc, then the solar energy is distributed along the latitude belts of the Moon. The solar constant at each latitude belt φ will be$S_{\varphi}(=Scos\varphi)$. For each latitude belt solar energy and emitted energy has to be balanced. If only daytime temperature for each latitude belt has to be estimated, then the followingequation has to be solved.

$$(\frac{\pi r^2}{2})S(1-\alpha)cos\varphi = \varepsilon б(\pi r^2){T_M}^4 \quad \ldots (2)$$

where α is the average albedo (= 0.11) and ε is the average emissivity (=0.97) (Ren et al., 2020) for the Moon surface. Here it may be noted that the solar energy is received by the half of the area of each latitude circle, whereas the thermal energy emitted by the area of the full circle.

One more factor has to be considered for Moon. The outgoing longwave radiation (OLR) from the Earthwill also be additional source of energy at Moon's surface. Then the equation (2) will be as follows.

$$\frac{S(1-\alpha)cos\varphi}{2} + E_{OLR} = \varepsilon б{T_M}^4 \quad \ldots (3)$$

where E_{OLR} is the outgoing longwave radiation from the Earth (average value = 240 W/m^2) (Glaser and Glaser, 2019).

Results

Solving equation (3) for the given values for each latitude one can get the following temperature profile (Fig. 1).

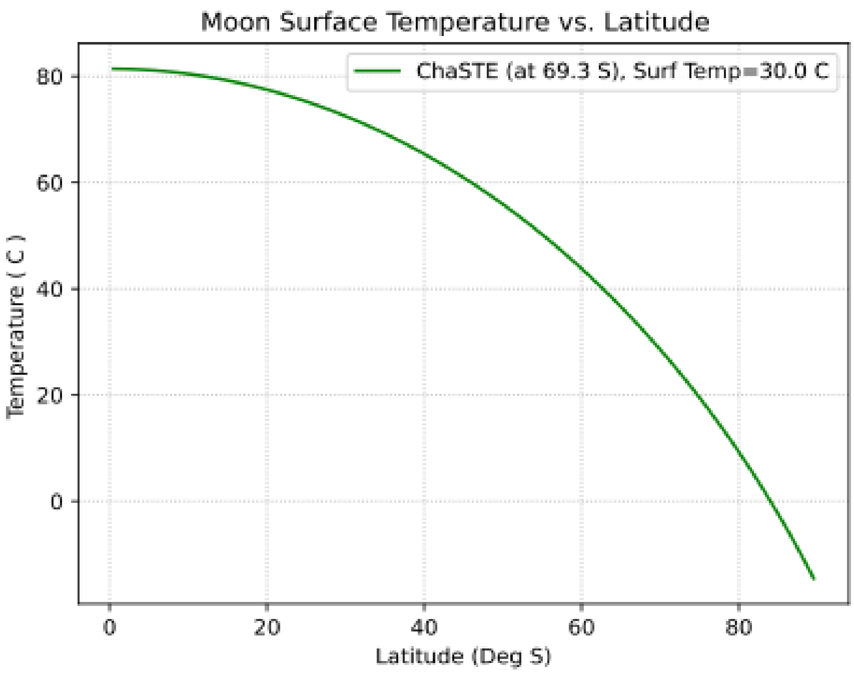

Figure 1:-Moon Surface daytime Temperature (C) along Latitude (S) belts with 1-D EBM

As Chandrayan-3 lander Vikram landed on 23 August 2023, the Earth was near aphelion.The exact date of aphelion was 6 July 2023. The landing site was (69.373 S, 32.319 E). So solar constant, S for Moon for that period and position is taken as 1350 W/m^2 .

The ChaSTE (Chandrayan-3 Surface Temperature Experiment) instrument (in Vikram lander) measurement is seen in Figure 2 (courtesy ISRO website www.isro.gov.in). The very first measurement by ChaSTE was published by ISRO in their website. It may be noted here that this published measurement is not calibrated data.

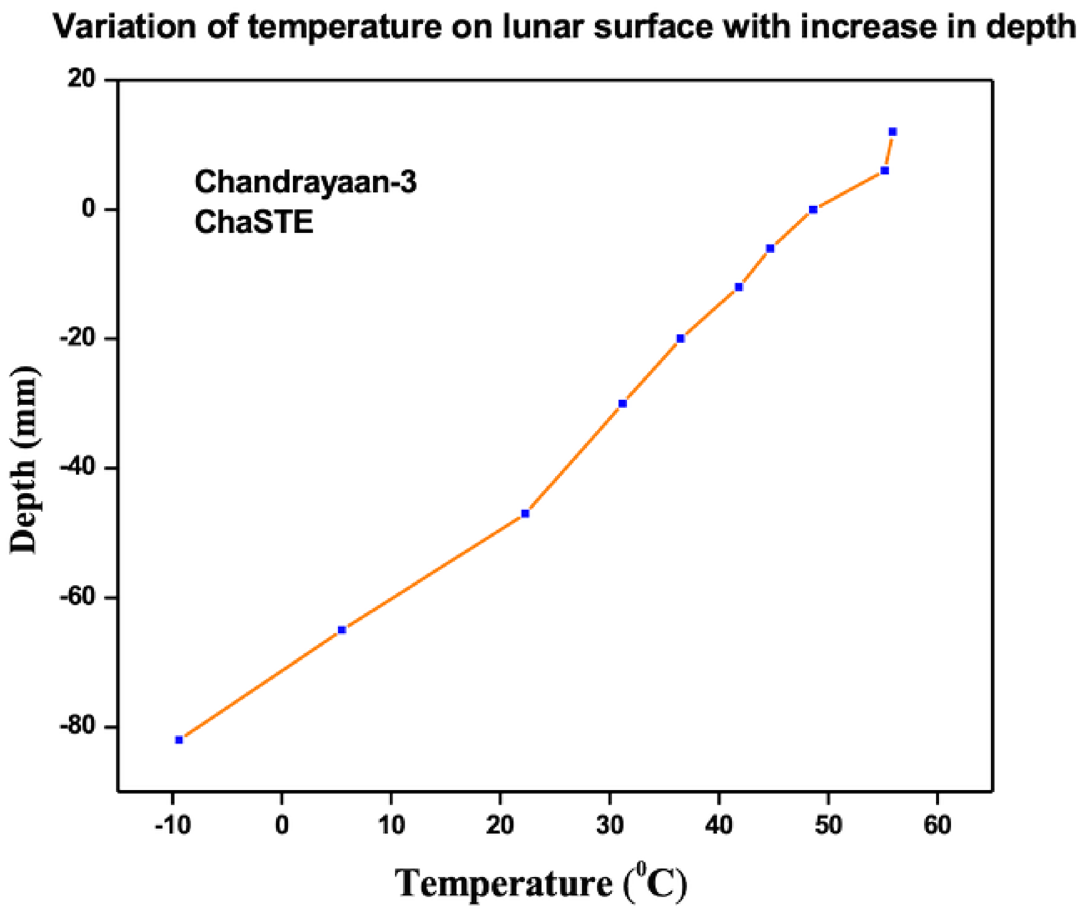

Figure. 2: ChaSTE measurements on Lunar surface

Discussion

It may be noted that there is some difference in the measured and simulated temperature at the surface. The ChaSTE value is higher than the simulated value. This may be due to the fact that the instrument might have been exposed to the direct sunlight. Another factor which may cause this difference is that if at the time of observation the Moon is in the direction of the reflected solar radiation from the Earth (S_{Ref}), this will provide additional source of energy. Considering the Solar constant for the Earth to be 1360 W/m^2 and the average albedo of the Earth to be 0.3, the value of S_{Ref} will be 408 W/m^2 . Then the equation (3) will be as follows.

$$\frac{(S+S_{Ref})(1-\alpha)cos\varphi}{2} + E_{OLR} = \varepsilon б T_M{}^4 \quad \dots (4)$$

Now solving the equation (4) for each latitude, one can get the following temperatureprofile (Fig.3).

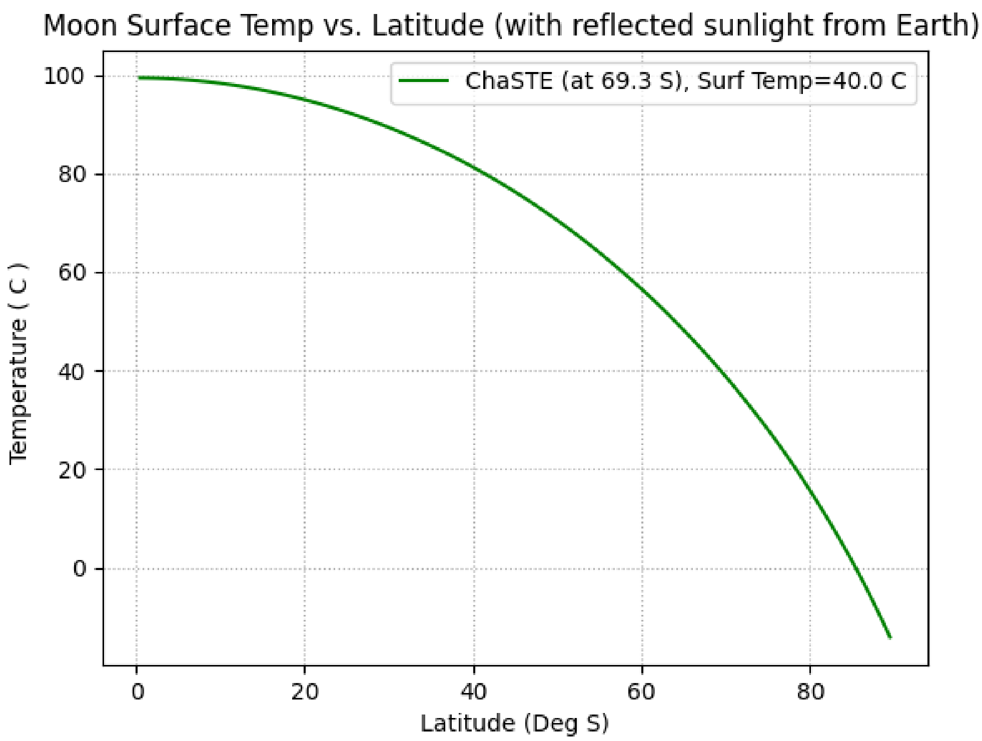

Figure. 3 Moon Surface daytime Temperature (C) along Latitude (S) belts with reflected sunlight from the Earth

If the instrument is exposed to the direct sunlight, the temperature may be 10 degree higher. In that case the observed value will be near 50 C above the surface, which is seen in Fig.2

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