Insulative Effect of Regolith on Lunar Sub-surface Temperatures

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1. Abstract

– Mapping of the lunar environment for the existence of water ice has relied on many indirect measuring techniques. One such technique is determining the maximum surface temperatures of the Moon. Temperatures determine the possibility of water ice, with the maximum temperature threshold for long term stability of water ice being 112K [1]. The maximum surface temperatures alone does not influence the possibility of lunar water ice existing in a region, instead the annual lunar thermal cycle and the insulating effect of the lunar regolith are able to sustain buried cold trap conditions less than 112K. The insulating effect of the lunar regolith is able to shield and insulate buried cold traps in a location with surface temperatures exceeding 200K.

2. Introduction

- The influence of the insulating properties of lunar regolith was shown in the sub-surface temperature tests performed by the Apollo missions, with no significant temperature fluctuations occurring below 80cm from the lunar surface even if surface temperatures fluctuated >200K between lunar days and nights [2]. Key to the thermal insulation of the regolith is its low density near the surface having the greatest insulative effect with the lunar regolith becomes denser with depth. As the regolith becomes denser, the thermal conductivity of the regolith increases [3].

Thermal modelling software, Oxford 3D, which mapped the lunar surface temperatures effect on the thermal influence at the lunar south pole sub-surface over a lunar year found areas with brief illumination with surface temperatures >120K could have stable water ice at depths of <30cm [4]. Further to this, the observation of water molecules or other hydroxyls by the NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA) in non-permanently shadowed regions (PSRs) on the Moon, indicated that water could be present beyond PSRs [5].

3. Oxford 3D Thermal Model

– Oxford 3D is able to determine the lunar surface temperature profile at high latitudes and subsequent sub-surface thermal profile by combining the one-dimensional sub-surface heat flow Hayne model and 3D shadowing and scattering effects[4]. O3DTM models the sub-surface temperature profile through a three-part simulation: (1) calculates the thermal energy flux at any given location through the lunar year; (2) determines the error of the calculated surface temperature with Diviner satellite surface temperature data; and (3) determines the sub-surface temperature profile over the lunar year.

Surface thermal modelling of the selected region was simulated at a resolution of 16ppd (pixels per degree). Sub-surface modelling was performed to a depth of 2.65m, beyond the thermal influence of surface temperature fluctuations, with 26 layers.

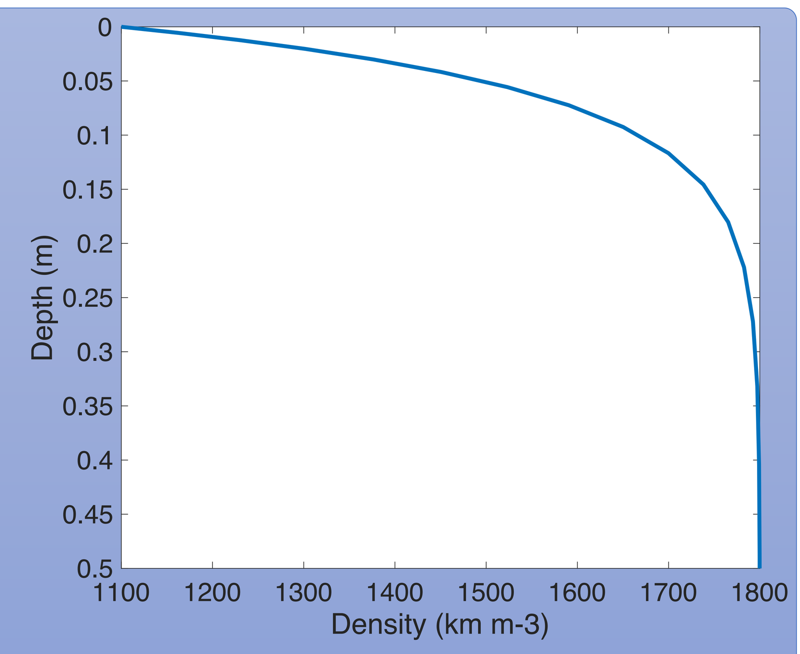


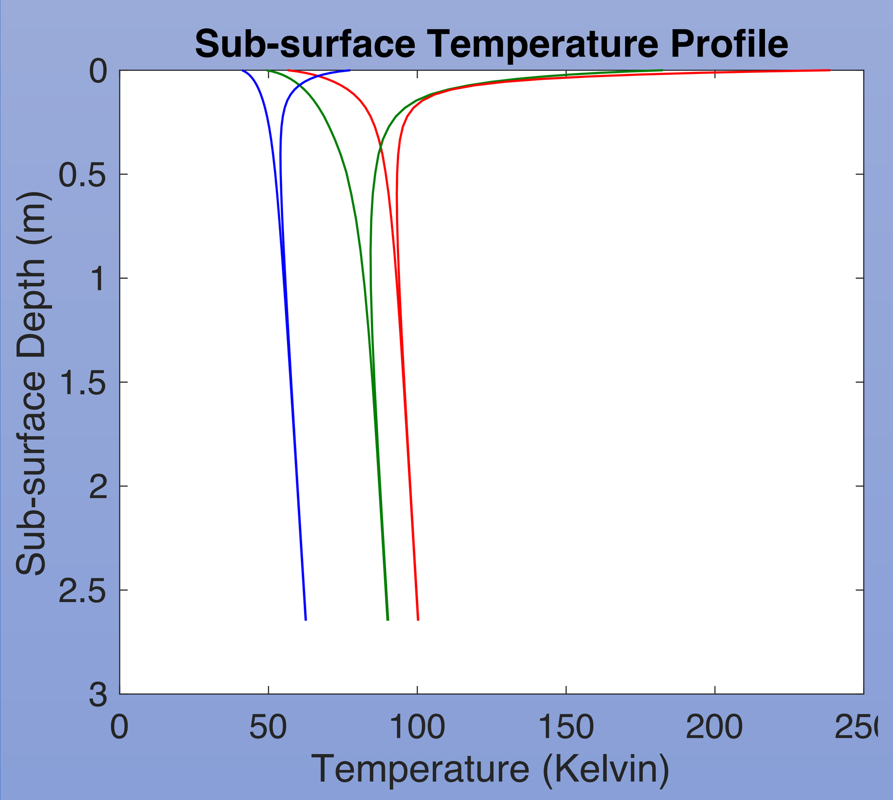
Figure 1: Regolith density profile using Vasavada sub-surface density profile equation [6] using ρ_s = 1100kg/m3, ρ_d = 1800kg/m3 and H = 0.06m [3].

4. Model Results

– Results from Oxford 3DTM indicate regions that have cold traps which could contain water ice can reside below lunar regions that have surface temperatures greater than 200K. Three sites were analysed around the modelled region, two with maximum surface temperatures (red and green) above 180K and a third site located within a permanently shadowed region (blue). The model determined that all three locations have the ability to sustain cold traps that are colder than 112K at depths greater than 20cm through to the maximum modelled depth of 2.6m.

Side projections of the surface temperature across the region, highlighted permanently cold traps with most other areas in the region having a maximum temperature of 150K. At a sub-surface depth of 60cm, the maximum temperature can be seen to be lower than 112K.

Further analysis of the results are required to determine the location, size and depth of each cold trap.



Site	Latitude	Longitude
1	-73.91	251.66
2	-79.09	244.91
3	-78.97	252.47

Table 1 and Figure 2: Three locations were mapped on the modelled region. The minimum and maximum sub-surface temperature profile provides an analysis as to the temperature extremes at each depth throughout the entire lunar year. Sites #1 (red) and #2 (green) are located inside the northern rim of a crater and with Site #1 experiences temperatures above 230K during the lunar summer and Site #2 reaching temperatures above 180K. Site #3 is located inside a permanently shadowed region with maximum surface temperatures not reaching above 80K. At depths >20cm through to the modelled depth of 2.6m, all three locations have sub-surface temperatures less than 112K.

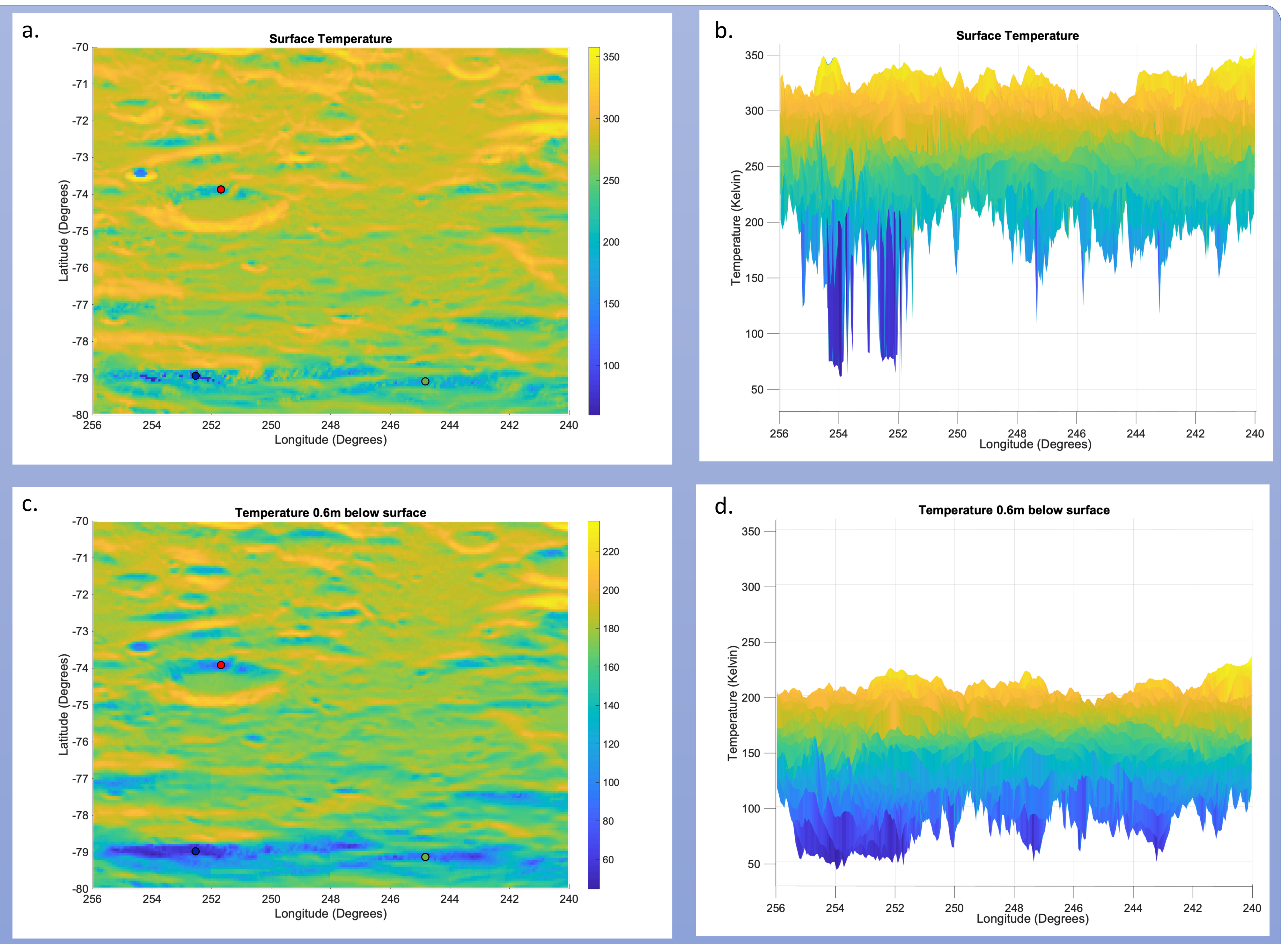


Figure 3: O3DTM modelled maximum surface (a, b) and sub-surface (c, d) temperatures across the region for an entire lunar year. The surface temperature across the region (a) and the temperature profile across the region (b) show a PSR located at approx. -79°S and 252-255°E, with most of the remaining area having a maximum surface temperature >150K. At 0.6m below surface, the maximum temperature through the entire lunar year across the band between 79°S and 80°S remains <120K, with two traps colder than 112K located between 246.5°-255.5°E and 242.5°-247.5°.

5. Model Accuracy

– There is currently no reference temperature profile for the lunar south pole region, so the surface temperature profile is compared with the measurements from the Lunar Reconnaissance Orbiter's Diviner Lunar Radiometer instrument (Diviner). Due to the resolution of the LOLA attitude data, O3DTM could have up to 30K difference between the model and Diviner temperatures at higher latitudes.

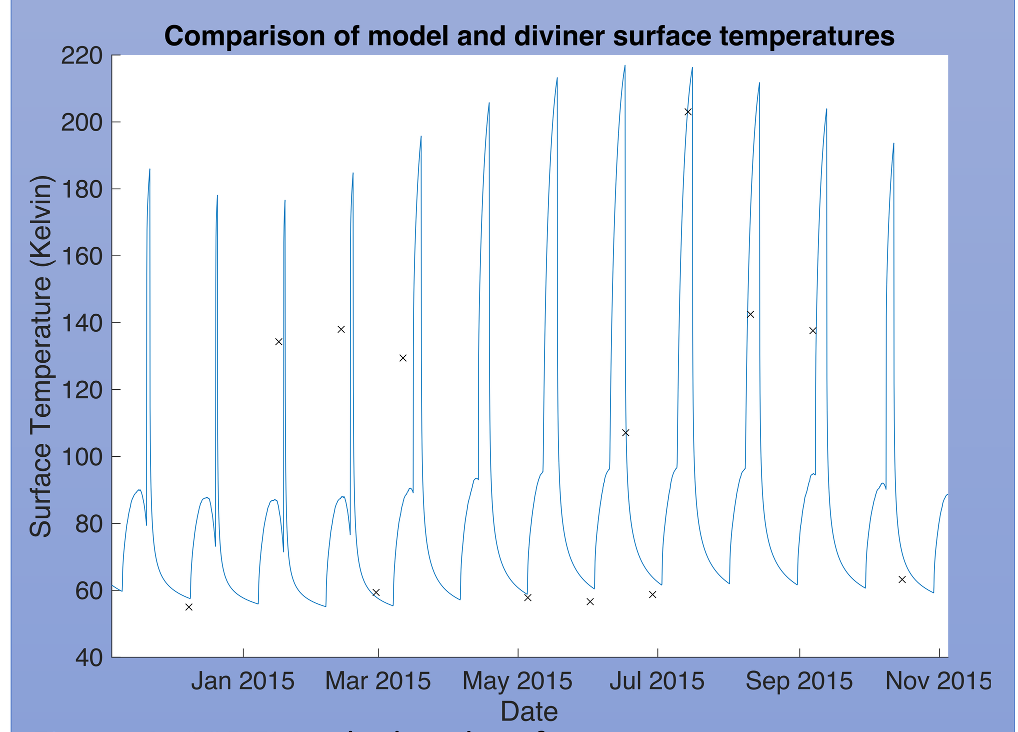


Figure 4: O3DTM calculated surface temperatures are mapped against recorded surface temperatures by Diviner at Site #1.

6. Conclusion

– Based on the modelling using Oxford 3DTM, cold traps that can sustain ice water (<112K) are able to exist beyond permanently shadowed regions, with some regions sustaining a buried cold trap when maximum annual surface temperatures exceed 200K. The depth of the cold traps is quite shallow and they are able to be continuously connected and quite large: 10's km in length and >3km wide.

References

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