Title

Thermal Modeling and Experiments Indicate a Fluffy Soil Layer Exists in Polar Regions, Endangering Lunar Rover Mobility

Abstract

I report on recent progress modeling the thermal properties of lunar soil including effects of porosity, temperature, vapor pressure, and ice content. This has been incorporated into a new modeling scheme and it successfully predicts the thermal behavior of the lunar surface as well as asteroid surfaces as those bodies rotate in the sun. An important question the model helps answer is whether the lunar surface is "fluffier" in the polar regions than the soil observed at the equatorial and mid-latitude sites that spacecraft have visited. Preliminary data from the Diviner Radiometer on the Lunar Reconnaissance Orbiter indicate the soil may have a thermal inertia that becomes systemically lower toward the poles, suggesting it may be fluffier with latitude dependence. One possible alternative explanation is that the thermal wave penetrates less deeply where the amplitude is smaller at higher latitudes, so perhaps non-homogeneity in the compaction of lunar soil with depth produces a non-linear response that only mimics fluffier soil. I modeled the thermal response of the soil using realistic lunar soil columns with randomly varying layers of compaction based on Apollo coring and cone penetrometry data. The results show the opposite effect than hypothesized: the non-linear response of the non-homogeneity mimic mores compacted soil toward the poles, not less compacted. This increases the argument that the soil is actually fluffier, and more so than previously believed. We have also performed experiments at UCF that predict the soil should indeed be fluffier at the lunar poles because the smaller thermal wave produces less thermally-induced compaction. This result is important because the depth of fluffiness corresponds to the depth that lunar rover wheels will shear and dilate the soil causing a loss of traction, and our data from 11 years of robotic mining competitions indicate that this O(10 cm) layer of fluffy soil poses a terrible risk for rovers to become stuck.