Three-Dimensional Thermal Modeling for the 2016 InSight Mission

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Introduction: The 2016 InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) Mission to Mars will make the first direct measurement of heat flux on another solar system body since lunar measurements during Apollo. It will also mark the first heat flux measurement of another solar system body that can benefit from the advent of modern computing tools. In anticipation of the InSight Heat Flow and Physical Properties Package (HP3) measurements, we are developing a series of 3-Dimensional thermal models to aid in interpretation of this unique data set.

Lander Scale Thermal Effects: InSight will robotically deploy the HP3 thermal probe and SEIS (Seismic Experiment for Interior Structure) seismometer within about 2 meters of the lander. The HP3 probe is designed to then burrow up to roughly 5m depth and measure the thermal properties and temperature gradient (with an instrumented tether) as a function of depth. Thermal conductivity will be measured with an active heater within the probe. A deck mounted radiometer will monitor a several meter patch of ground to constrain surface temperature forcing. These measurements share a common characteristic: at the distance scale of meters, InSight's scientific measurements cannot entirely escape the thermal impact of the lander itself (i.e. shadows, radiative coupling between the lander and underlying surface, obscuration of "cold" sky). Therefore, we seek to characterize the impact that the lander will have on the thermal environment at and below the Martian surface.

The InSight lander will have a net effect of both warming and cooling the Martian surface. Surface warming due to removal of high albedo dust by the thrusters will be directly measured by InSight's deck mounted radiometer. However, the actual surface temperature forcing function experienced by the subsurface probe will be modified by shadowing by and thermal radiation from the lander itself. The lander will potentially warm the surface and instruments, both day and night, by radiating heat from its interior electronics and stored thermal energy from the sun. Additionally, the lander will cool the surface by shadowing the ground below it.

Surface temperature effects from the lander may directly impact functioning of the HP3 and SEIS instruments. Advanced modeling of temperatures in the instrument work area can help identify the best locations to mitigate these effects. Additionally, heating or cooling of the surface will propagate into the regolith, directly affecting the thermal gradient that will be measured by HP3. Though HP3 is designed to reach depth quickly to avoid this surface thermal forcing, careful modeling of the propagation of surface temperatures to depth will greatly enhance understanding of regolith thermal properties and provide a contigancy plan for measuring heat flux if the probe does not reach its full depth.

Lander Scale Modeling: To examine the effect of the lander on surface temperatures, we have used Comsol Multiphysics to create a simplified model of the lander, Martian regolith, and solar insolation falling on both. This builds on past models examining the effect of a lander on heat flow measurements [1, 2]. The lander is typically modeled as a 300 polygon shape including the lander deck, body and solar panels. Models including conductive lander legs (such as shown if Figure 1, which shows results from roughly noon at Northern Winter Solstice) were also examined to examine the effect of thermal conduction into the ground, but this was found to be negligible.

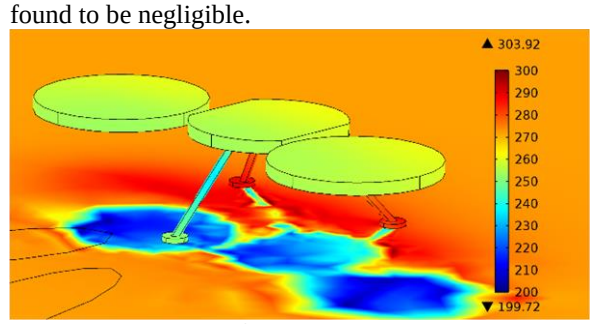

Figure 1: Sample simplified InSight lander model snapshot of roughly noontime temperatures near Northern Winter Solstice.

The regolith thermal properties model is adapted from Piqueux and Christensen [3,4]. Regolith thermal conductivity is temperature, pressure, and grain size dependent. We choose a nominal 250 micron grain size regolith with constant 40% porosity to match TES thermal inertia results. Gas conductivity dominates intergrain heat transfer and is both temperature and pressure dependent. Pressure is held constant at 6 torr for our nominal landing site location at 4ºN, 135ºE. Sky temperatures are taken from the KRC model [5] for given atmospheric dust opacities (all models here show τ = 0.2). Model layers increase thickness and a function of depth, beginning with surface layers of 1mm thickness.

Temperatures of the unaffected surface are found to vary from ~195-295K, with yearly average temperatures around 230K, consistent with KRC model results and preliminary Rover Environmental Monitoring Station (REMS) measurement at the nearby Mars Science Laboratory landing site [6].

3D Model Results: When the lander is added surfaces below the near the lander (which includes the work area where the HP3 and SIES instruments will be deployed) are calculated to reach up to 325K due to reflected light and heat being reradiated from the lander.

Figure 2 illustrates surface temperatures along a North-South transect through the lander (assumed to be pointing due South). Variations in temperatures of unaffected regolith have been removed. This figure shows that areas below the lander had maximum yearly temperatures up to roughly 20K above surrounding regolith. However, daytime shadow temperatures below the lander could dip to as much as 105K cooler than illuminated surfaces nearby. The net effect is a roughly 5K increase in mean annual temperatures near the lander (in the work area) and 10K decrease in mean annual temperatures below the lander.

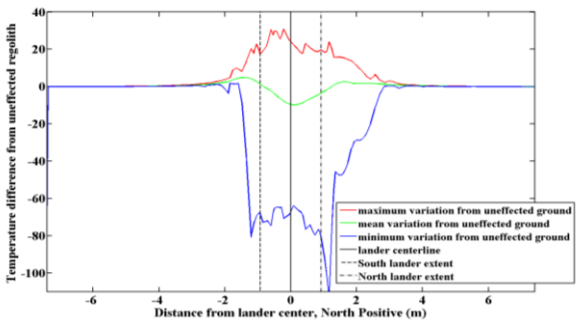

Figure 2: Maximum, mean and minimum temperatures of the surface around the modeled InSight lander over a period of 1 Mars year. Unaffected regolith temperature variations have been removed, so this figure illustrates temperature deviations caused by the lander.

2D Model Extrapolations: Ideally, one would run this full-up model for the entire length of the InSight mission to examine the propagation of thermal perturbations from the lander to depth. However, at current, models longer than 1 Mars year are computationally expensive (currently 1 year equals roughly 10 days of compute time). As seasonal perturbations will typically damp out in the top meter for our model regolith, one can approximate the long term propagation of surface temperatures to depths where the HP3 probe will measure heat flux by applying the surface yearly average temperature as a constant surface boundary condition.

Figure 3 illustrates two-dimensional thermal model results for temperatures below the lander after 5 Mars years. A steady state yearly mean temperature is assumed at the surface boundary (the green curve from Figure 2 plus an average surface temperature- assumed only 232K in this model). A lower boundary heat flux of 30mWm^{-2} is assumed, and is used to set an initial steady state temperature.

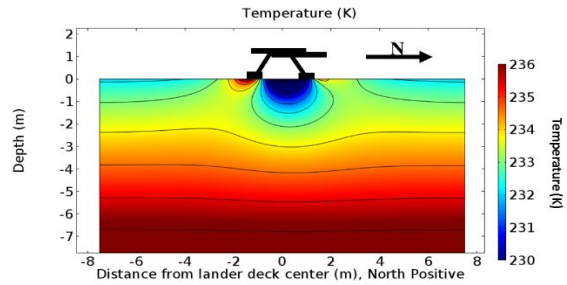

Figure 3: 2D model results for temperatures below the InSight lander after 5 Mars years assuming a steady state forcing of the 3D lander model.

Figure 4 illustrates the effect that this modeled surface temperature will have on the quantity InSight desires to measure, local heat flux. In this simplified model, one can see that measurements of heat flux will eventually be effected by propagation of heat from the lander-effected surface.

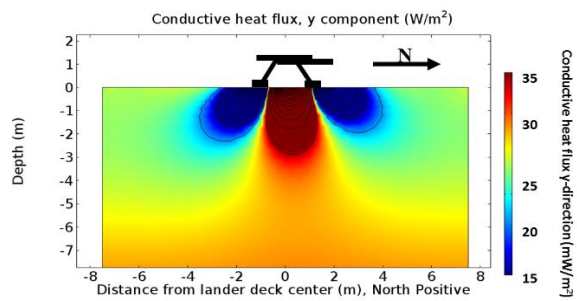

Figure 4: 2D model results for vertical heat fluxes below the InSight lander after 5 Mars years assuming a steady state forcing of the 3D lander model.

This has been taken into account in mission planning, as HP3 is to reach 5 meters depth in 60 days, not 5 Mars years, but is important to quantify. Deriving heat flux requires both a thermal gradient and thermal conductivity measurement. In the Apollo 15 heat flow experiment, thermal conductivity of the regolith as measured by and active heater within the probe was biased high due to compaction [7]. Propagation of surface temperature forcing to depth ended up being the primary way regolith thermal properties were accurately measured [8]. HP3 has been designed to limit error in its active heating measurement of thermal conductivity, but models such as those described here will greatly enhance confidence in these results.

References:[1] Grott Planetary and Space Science 57, 2009, [2] Keifer W., Planetary and Space Science 60, 2012, [3] Piqueux and Christensen, JGR, 2009, [4] Piqueux and Christensen, JGR, 2011[5]Keifer H., JGR, 2013, [6] Hamilton, # 1719, LPSC 2013,[7]Grott *et al.*, JGR,[8] Langseth *etal.*,1976, LPSC 7.