COMPARISON OF NUMERICAL MODELING AND TEMPERATURE RECORDS FROM THE MARS PATHFINDER LANDING SITE

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Introduction: Knowledge of temperature variations in the Martian regolith are essential to the accurate modeling of water and carbon dioxide phase behavior and mass transfer. Under Martian conditions, a 20°C change in temperature results in an order of magnitude change in equilibrium water vapor pressure and a 15% change in diffusivity [1]. Various approaches to predicting surface and near-surface temperatures have been utilized to predict ice stability on and under the surface [2 - 5] but few have been calibrated against measured surface temperatures. The purpose of this study was to do this on both diurnal and annual time scales at a site where accurate temperature records and thermophysical surface properties are available.

Modeling: Euler forward finite-difference was used to predict temperature profiles in Martian regoliths as a function of Ls, latitude, regolith physical properties (thermal conductivity, density and heat capacity), solar angle calculated from the local time, distance of Mars from the sun, albedo, and emissivity. The time resolution was 1 second and the vertical resolution was 5 mm to a depth of 8 m (1600 elements), which is deeper than 5 annual thermal skin depths. The convergence criteria was 0.1°C for all times and depths. Effects considered included solar radiation both unabsorbed and scattered by the atmosphere with the sun's position recalculated every 1 second, radiation up from the surface, radiation down from the atmosphere, conduction into the ground and 30 mW/m^2 of geothermal energy. Atmospheric convection was addressed qualitatively and latent heat effects from water and carbon dioxide were excluded for now. No adjustable input parameters were employed, only measured physical and astronomical data at the landing site.

A search for surface temperature vs. time-of-sol data turned up no sets with data on hourly time scales along with reasonable estimates of local physical properties, but an excellent data set of near-surface temperatures was extracted from Mars Pathfinder (MPF) results. In addition, daily maximum and minimum surface temperatures were recorded by the Thermal Emission Spectrometer (TES) on the Mars Global Surveyor (MGS) for several years. Data from both timescales were compared with the model to validate our computational approach.

Thermophysical Properties at the MPF Landing Site: The model requires input values of the regolith's thermal conductivity, the product of its bulk density and heat capacity, albedo and emissivity. At the MPF's location, 19.28°N and 326.5°E, the thermal inertia has been estimated from MGS-TES data is 387 J/m^2 s$^{1/2}$ K [6]. This number is the product of thermal conductivity, bulk density and heat capacity, and the last two of these can be estimated reasonably to get the value of the thermal conductivity. Heat capacity of basalts ranges from about 600 – 1000 J/kg K, so a value of 800 was taken. Bulk density was taken to be 2000 kg/m^3, taking into account the blocky nature of the landing site, and this left a reasonable value of 0.0936 W/m K for thermal conductivity. For albedo, the MGS-TES gave 0.19 [6] and the surface emissivity was set at 0.95 [7].

An atmospheric optical depth of 0.5 was used in a solar influx model that took into consideration both atmospheric absorption and scattering [8].

Comparison with Diurnal Pathfinder Data: Following its landing, MPF transmitted back temperatures taken by three sensors located 0.25, 0.5 and 1.0 m above the ground at various sampling rates for 76 sols. Few sols had complete coverage but, when all 76 sols are stacked together, they give a set of temperature profiles just above the surface at very high temporal resolution, as shown by the points in Figure 1. It is thought that actual Mars daytime surface temperatures exceed local atmospheric temperatures by at least several degrees [9, 10] and, in fact, the sensors closer to the ground tended to give slightly higher temperatures during the daytime. MPF landed on 4 July 1997. Since the temperature data collection spanned only about 10% of a year, seasonal changes across this interval are small so we ran the model for diurnal solar conditions at the middle of that time period: 12 Aug. 1997 on Earth. For that time and at MPF's location on Mars, Ls = 162.5°, there were 12.35 Martian hours of daylight, the sun achieved a maximum elevation of 78.1°, and Mars was 1.54 AU from the sun, giving an unattenuated intensity of 607 W/m^2 and a total integrated energy to the surface of 17.2 MJ/m^2 in one sol. Figure 1 shows a comparison between the stacked near-surface data from MPF and the model results using the input parameters described above.

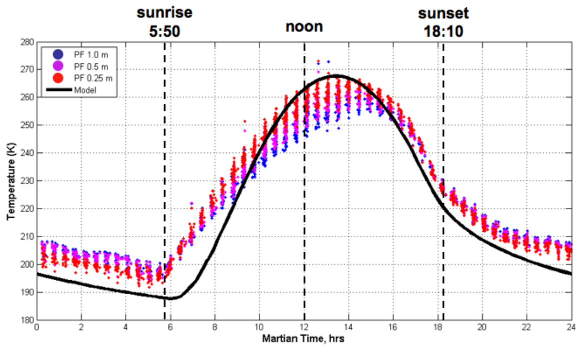

Figure 1. Comparison of near-surface Mars Pathfinder temperature data and diurnal finite-difference model predictions of surface temperatures during the course of one sol using physical and astronomical data of the landing site as model input.

The agreement is quite close in both shape and magnitude. As mentioned above, the actual daytime surface temperature is probably a bit warmer than even the 0.25 m MPF data, so the model should lie slightly higher than the data points. For these inputs, the model predicts the surface to be a few degrees higher during the heating in the middle of the day. Similarly, nighttime surface temperatures should be slight cooler than air temperatures, much like derserts on Earth.

Comparison with Annual MGS-TES Data: Maximum daytime and minimum nighttime surface temperatures were measured for almost four Martian years and made available as a color-coded QuickTime movie [11]. Surface temperatures were extracted for the MPF landing site for one year at intervals of 60° of heliocentric longitude as well as in the middle of the period over which data were taken from the surface (Ls = 162.5°). The model was run in annual mode, recalculating the sun's position and distance as well as atmospheric absorption every second over a period of one year.

A comparison of measured data and model results are shown in Figure 2. The uncertainty on the measured temperatures is approximately +/- 6K due to the need to match colors to back out quantitative values. MPF sits in a Martian latitude that exhibits almost the smallest annual temperature variation on the planet. This is because aphelion of Mars' rather elliptical orbit occurs at Ls = 71°, very close to the northern hemisphere summer solstice (90°). Conversely, perihelion occurs at 251°, near the winter solstice (270°).

Even with this data scatter, the agreement is quite satisfactory. The model reflects the greater annual variation in daytime maxima compared to nighttime variations. Overall temperature matches are somewhat better during the daytime, but all fell within approximately 10K.

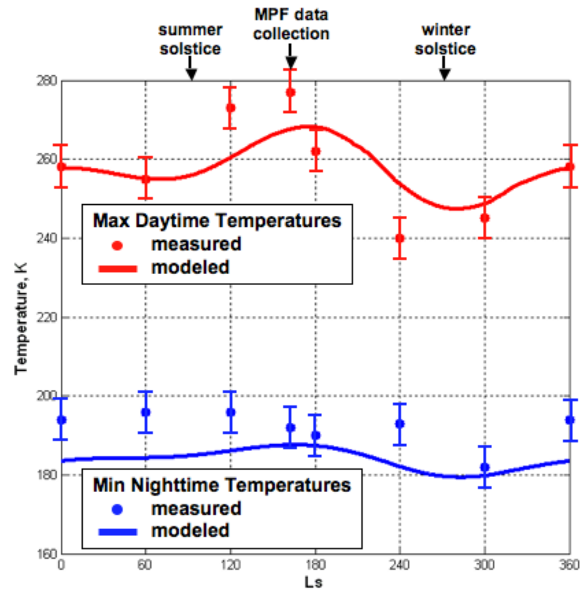

Figure 2. Comparison of day and night temperatures from the MPF landing site, measured by the MGS-TES, to the annual finite-difference model predictions.

Conclusions: Our numerical model for diurnal and annual-scale regolith temperature variations seems to be validated due to strong agreement with the two sets of measured T vs. time data from two different spacecraft. For the future, the scope of the model will be extended to include thermal effects of condensables. Then the same calculational approach will be used on the temperature-dependent mass transfer and phase behavior of water vapor in the regolith.

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