TEMPERATURE FIELDS AT MARS LANDING SITES: IMPLICATIONS FOR SUBSURFACE BIOLOGY. Rick Ulrich[1,2], Rob Pilgrim[1], Vincent Chevrier[1], Larry Roe[1,3], Tim Kral[1,4]
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Introduction: While average temperatures on Mars may be too low to support terrestrial lifeforms or aqueous liquids, diurnal peak temperatures over most of the planet can be high enough to provide for both beneath the surface for at least some fraction of time. These depths are also sufficient to shield lifeforms from UV solar radiation. A thermal model was applied to the five successful landing sites to demonstrate this dynamic temperature field on and under the surface at these well-characterized locations. The landing sites vary significantly in subsurface temperatures throughout the year with Viking 2 being the coldest and two MER sites the warmest. At the MER sites, the top few mm's reach 273K every sol for almost 2/3 of the year and 253K for the entire year. The penetration depth of diurnal temperature changes is about 4 cm and, since peak heating is driven by the diurnal scale, temperatures conducive to liquids and/or life penetrate at most a few cm's below the surface at any location, within range of simple scoops.

Temperatures for Life and Liquids: Microbial life requires a liquid phase for growth and replication and might be supported below 273K if stable aqueous liquids are available. A comparison of methanogens found in Siberian permafrost with methanogens from non-permafrost habitats under Martian conditions showed that the permafrost-derived methanogens exhibited much greater survival [1]. Studies of methane evolution by a natural community of methanogens in permafrost demonstrated metabolic activity in the permafrost organisms down to 256.5K [2]. In another study, permafrost bacteria were able to incorporate ^{14}C-labeled acetate into lipids at temperatures as low as 253K [3]. Metabolic activity at subfreezing temperatures is dependent on unfrozen water strongly bound as thin films to soil particles. At temperatures below 258K, unfrozen water approaches asymptotically 1-2% [2], which is sufficient to support metabolic activity. In frozen soil, soil particles and microbial cells are covered by thin films of liquid water.

At Martian pressures, pure water will be solid below 273.16K but concentrated ionic solutions can be fluid at much lower temperatures. Eutectic solutions of chlorides can remain liquid down to 223K for $CaCl_2$ or 247K for NaCl [4], while sulfates have higher eutectics, around 268K [5]. We have recently characterized the low-temperature behavior of concentrated aqueous solutions of salts known to be present on Mars [3]. This work was carried out on various solutions of Fe^{2+}, Fe^{3+}, Mg^{2+}, and Ca^{2+} with Cl^- and SO_4^{2-} up to 65% by weight (for $Fe_2(SO_4)_3$). This indicates that brines made up of compounds known to exist on Mars might be able to be stable in the liquid phase.

Modeling: An Euler forward finite-difference procedure was used to predict regolith temperature profiles from the immediate surface down into the Martian sub-surface as a function of time of Martian year (Ls), time of sol, latitude, regolith physical properties (thermal conductivity, density and heat capacity), distance of Mars from the sun, and surface albedo and emissivity. The time resolution was 1 second and the vertical spatial resolution was 1 mm down to a depth of 8 m (8000 elements), which is over 5 annual thermal skin depths. The convergence criteria was 0.1K for all times and depths. Effects considered included direct solar radiation to the surface, recalculated every 1 second based on solar altitude and distance, radiation up from the ground using an emissivity of 0.95, conduction through the near-surface region, and 30 mW/m^2 of geothermal energy from below [6].

Temperatures at the Landing Sites: Figure 1 shows the predicted surface and subsurface temperatures at the MPF landing site throughout the sol at Ls = 162°, in the middle of the mission. The diurnal penetration depth is 4.7 cm so, by 10 cm, the temperatures range is only +/- 3K around the average deep temperature of 220K. Figure 2 shows that this sol is near the maximum temperatures at this location; at midyear the surface temperature can reach just below water's triple point. Points for comparison include surface temperature estimates from the Ames Global Circulation Model and from thermocouples on the MPF meteorological mast located 25 cm above the surface.

The depth to various diurnal maximum temperatures are shown for MPF in Fig. 3 and for Opportunity in Fig. 4. If we take as a benchmark the 253K temperature demonstrated to support permafrost metabolism [3], it can be seen that this temperature is reached as some depth about ¾ of the year at MPF and all year at Opportunity. The depths that reach 253K in the middle of the day are 30K above the average temperature at that time. To balance this out the same location drops at night by about 60K to 30K below average, or 193K (Fig. 5).

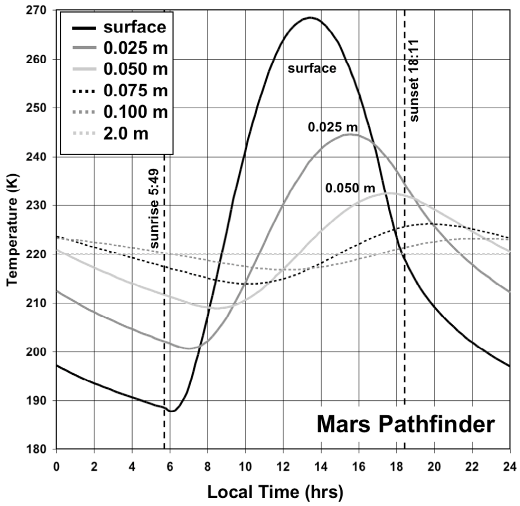

Figure 1. Surface and subsurface temperature profiles at the MPF landing site for a typical day in the middle of the mission (Ls = 162°).

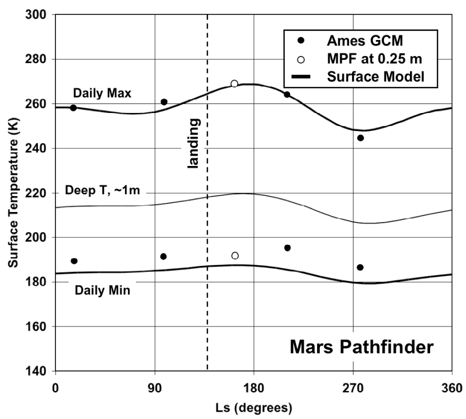

Figure 2. Maximum, minimum and deep temperatures throughout the year at the MPF landing site.

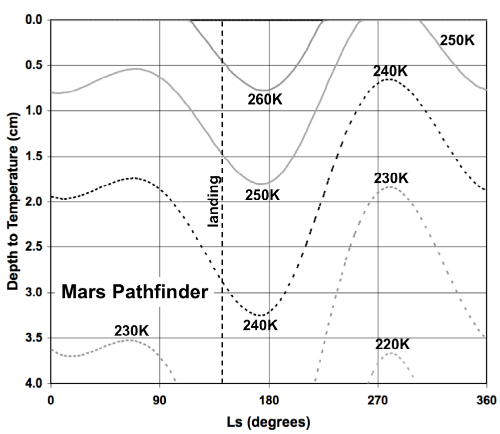

Figure 3. Depth to daily maximum temperatures at the MPF landing site.

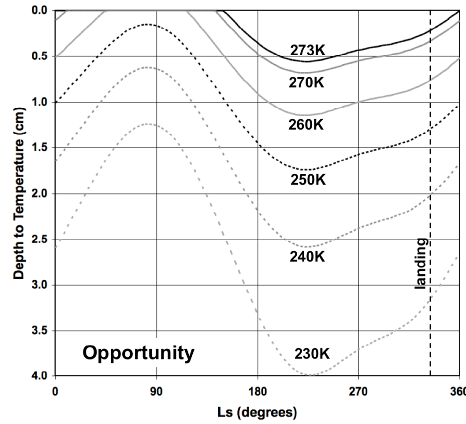

Figure 4. Depth to daily maximum temperatures at the Opportunity landing site.

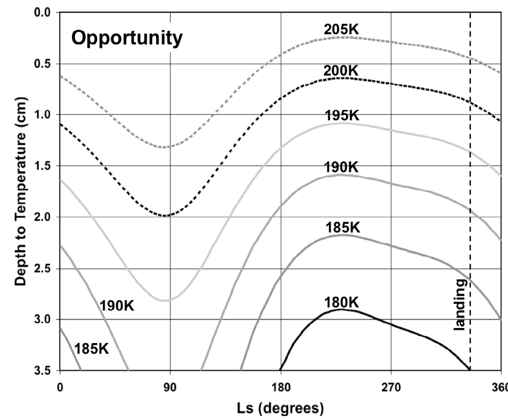

Figure 5. Depth to daily minimum temperatures at the Opportunity landing site.

Conclusions: Requirements for subsurface life on Mars include sufficient temperature to support metabolism and liquid water to provide for nutrient transport. Metabolic activity in permafrost bacteria has been demonstrated down to 253K (3) and aqueous solutions containing salts known to exist on Mars can remain liquid at similar temperatures.

253K is reached at diurnal peak heating for at least some parts of the year at all five successful landing sites on Mars. At the coldest site, Viking 2, this occurs for only about 20% of the year but at Opportunity it happens every sol. The price that is paid for these higher than average temperatures is that the same locations then must suffer lower than average temperatures at night.

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