Soil physical measurements by the Thermal and Electrical Conductivity Probe aboard NASA's Mars Phoenix Scout Mission

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Abstract
On May 25, 2008, NASA's Phoenix Scout Lander touched down on the Martian northern polar region. Part of Phoenix's payload was the Thermal and Electrical Conductivity Probe (TECP). During the 150 day mission, TECP probed the soil at the Phoenix landing site measuring multiple soil physical properties including dielectric permittivity, electrical conductivity, thermal diffusivity, volumetric heat capacity, and thermal conductivity. TECP thermal properties measurements ground-truthed satellite derived thermal inertia measurements and indicated dry, low bulk density soil at the landing zone. TECP detected no measurable electrical conductivity, again indicating dry soil. Dielectric permittivity of the soil increased significantly over the course of the mission alluding to vapour phase transport of water from the atmosphere to the soil as the soil cooled in the Martian Autumn.

Key Words
Mars, Phoenix, thermal properties, dielectric permittivity, electrical conductivity, soil water content

Introduction
As part of the 2007 Phoenix Scout Mission to Mars, TECP had the unique opportunity to make unprecedented *in situ* measurements of Martian soil physical parameters in the northern polar region. This region is characterized by a thin (~10 cm) soil layer on top of water ice. Phoenix's mission goals were to study the subsurface ice, search for evidence of past liquid water, and characterize present-day climatic processes. To that end, TECP was equipped with several measurement functions that are very sensitive to unfrozen water in the soil.

Methods
Soil thermal diffusivity and volumetric heat capacity were measured with a modified dual needle heat pulse (DNHP) technique. Soil thermal conductivity was measured simultaneously using the DNHP technique and a modified single needle heat pulse technique. Both methods were developed specifically for this mission.

Dielectric permittivity was measured using a simple capacitance type sensor based on Decagon's ECH_2O sensors at a measurement frequency of 6 MHz to stay below the relaxation frequency of tightly bound water films. Electrical conductivity was measured with a simple voltage divider at 1 kHz. Both electrical measurements were optimized for maximum sensitivity in the dry soil range with the goal of detecting trace amounts of unfrozen water in the soil.

All measurement functions (including several others outside the scope of this paper) were packaged in an aluminum enclosure that also served as the mechanical interface to the Phoenix Robotic Arm. Four metal needles served as the heated needles for the thermal properties measurements and also as electrodes for the electrical properties measurements (Figure 1). More details on the TECP design can be found in Zent *et al.* (2009a).

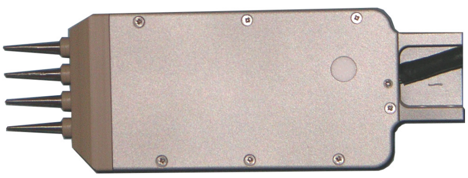

Figure 1. Picture of Thermal and Electrical Conductivity Probe.

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Results
TECP measured soil thermal conductivity of about 0.085 W m^{-1} K^{-1}, which is far lower than even low density Earth soils. However, this result is consistent with dry soil at low (Martian) atmospheric pressure. TECP measured volumetric heat capacity of about 1.05 ML m^{-3} K^{-1}, which is lower than a typical mineral based soil on Earth. This indicates very low bulk density soil at the landing site. Measurements of thermal diffusivity yielded a diurnal damping depth of approximately 6 cm, which is consistent with the ice depth observed at the site. Combining thermal conductivity and volumetric heat capacity into thermal inertia (thermal admittance) yielded values of about 250 J m^{-2} $s^{-1/2}$ K^{-1} for the landing site. These results agree well with data obtained by the Thermal Emission Spectrometer aboard Mars Global Surveyor.

The electrical conductivity of the landing site never reached the lower measurement threshold of the TECP instrument, indicating an absence of continuous water films between the TECP electrodes. The magnitude of measured dielectric permittivity was consistent with dry Earth soil. Increases in dielectric permittivity late in the mission as the soil cooled during the Martian Autumn allude to robust scavenging of atmospheric water by the soil. However, the magnitude of the dielectric permittivity change is larger than would be expected from this type of scavenging, so additional data analysis and interpretation is ongoing. See Zent *et al*. (2009b) for more details on the initial results obtained by the TECP instrument.

Conclusions
The TECP instrument aboard the Phoenix mission performed flawlessly over the course of the mission, and was able to successfully characterize the thermal and electrical properties of the soil near the Phoenix landing site over space and time. None of the TECP measurements indicated that liquid water is present at the Phoenix landing site.

References
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