# Thermal conductivity of soils as affected by temperature

Kathleen M. Smits, Toshihiro Sakaki and Tissa H. Illangasekare
Center for Experimental Study of Subsurface Environmental Processes, Colorado School of Mines,

**Abstract.** In the shallow subsurface immediately below the land-atmospheric interface soil moisture conditions are constantly changing. Due to the dynamic nature of this region that is largely affected by thermodynamic processes due to the atmospheric climate conditions and hydrologic stresses, knowledge of soil thermal properties over a wide range of soil moisture and temperature conditions is necessary to accurately describe heat flow in arid environments, in the area surrounding heat generating equipment buried in the ground, in the vicinity of buried objects such as landmines and under forest and range fires. Soil thermal conductivity, however, is difficult to measure at high temperatures due to the lack of suitable measurement devices and the potential for measurement-induced changes such as thermally induced water movement caused by increased soil temperatures when using line heat source thermal probes. Therefore, thermal conductivity data is often scarce and incomplete, and very often limited to specific soils and selected moisture content values under ambient temperature conditions. Such data is needed in conducting model analysis to obtain insights and making predications of the system behavior under different climate and hydrologic stresses. Due to a lack of comprehensive experimental data under varied soil moisture and temperature with a reasonably high resolution, empirical relationships that are used in models often do not accurately predict the thermal conductivity of sands as a function of both soil moisture and temperature. In this study, thermal conductivity (l) was measured for two laboratory test sands (#30/40 and a field sand) with different mean grain sizes and particle size distributions under varied water content (q) and temperature (30-70$^{o}$C). Several recent sensor based technologies were integrated into a Tempe cell modified to have a network of sampling ports, continuously monitoring water saturation, temperature, and soil thermal properties. For the test soils studied, l-q data showed the thermal conductivity increased with an increase in temperature; the threshold temperature exists between 50 and 60$^{o}$C. At temperatures 22-55$^{o}$C, the change in thermal conductivity with temperature was not measurable. Thermal properties measured in this study were then compared with independent estimates made using empirical models reported in literature. In general, good agreement was observed for most l-q data at low temperatures but did not agree with measured values at high temperatures. These experimental results highlight the importance of properly accounting for the affect of temperature on the thermal conductivity of soils and the need for accurate experimental data sets to improve modeling efforts.