5.3 Thermal Conductivity
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5.3.1 Introduction

The three key soil thermal properties that need to be taken into account when addressing heat flow in soil include (i) the soil thermal conductivity ($\lambda; \text{W m}^{-1} \text{K}^{-1}$), which describes the soil’s ability to transmit heat; (ii) the soil volumetric heat capacity ($\rho c; \text{J m}^{-3} \text{K}^{-1}$) (Taylor & Jackson, 1986; Section 5.2), which describes the soil’s ability to store heat; and (iii) the soil thermal diffusivity ($\alpha = \lambda/\rho c; \text{m}^2 \text{s}^{-1}$) (Jackson & Taylor 1986; Section 5.4), which describes the “rate of transmission of temperature change” within the soil. While this section focuses on thermal conductivity, some of the methodologies discussed will at times draw on knowledge of the other thermal properties.

Heat flow through soils can be by conduction, convection, radiation, and transfer of latent heat. Conduction is responsible for heat flow through the linked solid components of soil, while conduction, convection, and radiation can act in parallel to transport heat across soil pores. Although some air movement may be involved, convective heat transport takes place mainly through movement of water in liquid and/or vapor form across soil pores. Radiative heat transport is usually ignored within soils, but is an important process in terms of heat exchange at the soil surface. Latent heat transport is an additional process that transports heat across soil pores that are subjected to temperature gradients. This occurs through vaporization of soil water from the hot side and subsequent condensation on the cold side of the soil pore.

Thermal conductivity ($\lambda; \text{W m}^{-1} \text{K}^{-1}$) describes the soil’s ability to transmit heat (mainly by conduction). It is usually defined as the quantity of heat that flows through a unit area in a unit time under a unit temperature gradient, as described by Fourier’s law of heat conduction

$$\lambda = -G/\nabla T$$  \[5.3-1\]

where $G$ is the heat flux density ($\text{W m}^{-2}$) and $\nabla T$ ($\text{K m}^{-1}$) is the temperature gradient. A major constraint of this definition is that it implies conduction of heat in homogenous, isotropic, rigid materials—conditions that are seldom met in field soils. In these materials, the form of total soil thermal conductivity often includes both...