Development of a MATLAB-based Energy Transfer Model (METM) for Simulating Heat Transfer in Soil and Energy Exchange among the Atmosphere, Land Surface, and Vegetation Canopy

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Abstract: A MATLAB-based Energy Transfer Model (METM) was developed and evaluated at ten Soil Climate Analysis Network (SCAN) sites managed by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) across the southern United States. At each SCAN site, the top 100 cm of soil was divided into twenty layers, each 5 cm thick. Energy exchange among the atmosphere, land surface, and vegetation canopy, as well as heat transfer within the soil, was simulated by solving the non-linear partial differential equation (PDE) of energy balance. The PDE was discretized into twenty coupled energy balance equations using a second-order finite difference method with a semi-implicit numerical scheme.

The unknowns to be solved include land surface skin temperature and soil temperatures at 19 depths (5, 10, ..., 95 cm). Measured soil temperatures at 100 cm were used as boundary conditions, and initial soil temperature conditions were obtained by linear interpolation of measurements at 5, 10, 20, 50, and 100 cm. Energy sources and sinks in the topsoil (layer 1) include net radiation, sensible and latent heat fluxes, and ground heat flux at the bottom boundary. For layers 2 to 20, energy sources and sinks are defined by ground heat fluxes across the top and bottom of each layer. Soil thermal conductivity and heat capacity were parameterized as functions of soil saturation degree and sand and clay content, following methods from van Wijk and de Vries (1963), Johansen (1975), and Peters-Lidard et al. (1998). Canopy conductance for latent heat flux calculations was determined using Stewart's (1988) model, which accounts for solar radiation, humidity deficit, air temperature, and soil moisture deficit. Comparisons between simulated and measured hourly soil temperatures across the ten SCAN sites demonstrate that METM effectively captures hourly soil temperature variations, highlighting its potential to simulate energy exchange among the atmosphere, land surface, and vegetation canopy.