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Estimating Thermal Inertia with a Maximum Entropy Boundary Condition

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Thermal inertia, P [Jm-2s-1/2K-1], is a physical property the land surface which determines resistance to temperature change under seasonal or diurnal heating. It is a function of volumetric heat capacity, c [Jm-3K-1], and thermal conductivity, k [Wm-1K-1] of the soil near the surface: $P=\sqrt{ck}$. Thermal inertia of soil varies with moisture content due the difference between thermal properties of water and air, and a number of studies have demonstrated that it is feasible to estimate soil moisture given thermal inertia (e.g. Lu et al, 2009, Murray and Verhoef, 2007).

We take the common approach to estimating thermal inertia using measurements of surface temperature by modeling the Earth's surface as a 1-dimensional homogeneous diffusive half-space. In this case, surface temperature is a function of the ground heat flux (G) boundary condition and thermal inertia and a daily value of P was estimated by matching measured and modeled diurnal surface temperature fluctuations. The difficulty is in measuring G; we demonstrate that the new maximum entropy production (MEP) method for partitioning net radiation into surface energy fluxes (Wang and Bras, 2011) provides a suitable boundary condition for estimating P. Adding the diffusion representation of heat transfer in the soil reduces the number of free parameters in the MEP model from two to one, and we provided a sensitivity analysis which suggests that, for the purpose of estimating P, it is preferable to parameterize the coupled MEP-diffusion model by the ratio of thermal inertia of the soil to the effective thermal inertia of convective heat transfer to the atmosphere.

We used this technique to estimate thermal inertia at two semiarid, non-vegetated locations in the Walnut Gulch Experimental Watershed in southeast AZ, USA and compared these estimates to estimates of P made using the Xue and Cracknell (1995) solution for a linearized ground heat flux boundary condition, and we found that the MEP-diffusion model produced superior thermal inertia estimates. The MEP-diffusion estimates also agreed well with P estimates made using a boundary condition measured with buried flux plates. We further demonstrated the new method using diurnal surface temperature fluctuations estimated from day/night MODIS image pairs and, excluding instances where the soil was extremely dry, found a strong relationship between estimated thermal inertia and measured 5 cm soil moisture.

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