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The effects of soil vertical discretization, soil thermal properties, and soil heat convection by liquid water transfer on the water and energy cycles in a coupled land-atmosphere model

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The soil heat transfer is an important component in general circulation model (GCM), and accurate representation of subsurface thermodynamics is essential for earth system modeling. The accuracy of the soil thermodynamics simulation is affected by many factors: (1) the bottom boundary layer position used in numerical scheme; (2) the soil thermal property (heat capacity and thermal conductivity) parameterization; as well as (3) the physical processes considered in the model. However, the impact of their correct representation on the quality of the simulated climate is poorly documented, and the way state-of-the art land surface model (LSM) used for climate simulations account for them is highly variable. For instance bottom boundary layer position varies from 2 m to 10 m or even more (100 m), the parameterizations of the soil thermal properties not always account for the soil texture effects, and the soil heat convection process is neglected in most soil thermodynamics models.

In this work, we revisited the soil thermodynamics model included in the ORCHIDEE LSM in order (1) to determine the soil bottom layer depth which allows for simulating the annual cycle of temperature; (2) to improve the parameterization of the soil thermal properties (thermal conductivity and heat capacity) by accounting for both soil moisture and soil texture effects on the soil thermal properties; (3) to take into account the heat generated by liquid water movement in soil thermodynamics. The developpement of the parameterizations has been done in a 1-D framework where the results of the Finite Difference Method have been compared to the analytical solution. Sensitivity experiments with the LMDZ-ORCHIDEE coupled model (atmosphere-land component of IPSL-CM model) have been then designed to evaluate the impact of the soil thermal properties and soil heat convection on the water and energy cycles of the land-atmosphere.

Main results are: (1) the 8 meter soil depth is proposed as a minimum requirement for simulating the annual cycle of soil temperature; (2) the surface water and energy cycles are sensitive to the soil thermal property parameterization. A lower (higher) thermal inertia leads to smaller (larger) amplitude of surface soil heat flux. The soil temperature decreases (increases) with the decreasing (increasing) of soil heat diffusivity. The net radiation is also affected by soil thermal properties due to the variation of upward long-wave radiation (caused by surface temperature). The changing of net radiation is mainly compensated by the sensible heat flux. During the night, the air temperature is more affected by the soil thermal properties than that during the day. (3) The rain temperature is lower than the land surface temperature in most regions, which means that the rainfall cools the land surface. In daily or shorter (e.g., 3-Houly) time scales, the soil temperature (turbulent heat flux) varies about 0.05 K (+/- 6 W/m2) with the rainfall (its heat flux) equal 0-5mm/d (0-4 W/m2). The soil heat convection effects on surface turbulent heat fluxes are small (+/- 1 W/m2) on monthly scale.