Geophysical Research Abstracts
Vol. 15, EGU2013-5653, 2013
EGU General Assembly 2013

A simulation study of diurnal soil evaporation dynamics using a coupled water, vapour and heat flux model.

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The Richards equation is often used to simulate water flow in soils considering only isothermal liquid water flow. This implies the assumption that evaporation only takes place at the soil surface. When the soil surface is (partially) wet, the vapour pressure at the soil surface is assumed to be uniform and equal to the saturated vapour pressure so that the evaporation rate can be calculated directly from solving the soil surface energy balance and imposed as a flux boundary condition. For a dry soil surface, a certain threshold pressure head at the soil surface is used as a Dirichlet boundary condition so that the water flux in the soil to the evaporating surface can be calculated. In this contribution we compared simulations of soil evaporation by the Richards equation with a more physically based approach that considers coupled heat, vapour, and liquid fluxes in the soil. The parameterisation of diffusive vapour flux in the soil and through a boundary air layer at the soil surface in these coupled models is, however, strongly debated. Therefore, we investigated the effect of: (i) the enhancement of thermal vapour fluxes that is attributed to thermal non-equilibrium in the soil, (ii) the enhancement of vapour diffusion by turbulent pumping in the upper soil layer, and (iii) the resistance to vapour transfer in the air layer above a partially wet soil surface on simulated evaporation and its diurnal dynamics. For partially wet soil surfaces, the resistance of vapour transfer through the boundary air layer as a function of its thickness and the distance between evaporating surfaces leads to smaller evaporation rates than simulations that assume a uniform vapour pressure in the air at the soil surface. Since 1-D models cannot resolve spatial variations in vapour pressure at the soil surface, this effect cannot be simulated by these models but needs to be parameterized in their boundary conditions. For dry soil surfaces, the simulated diurnal dynamics of soil evaporation differed between the Richards model and the coupled model and were sensitive to the parameterisation of vapour diffusion in the soil. In case vapour diffusion was enhanced by turbulent pumping and enhancement of thermal vapour fluxes was not considered, the diurnal dynamics of the evaporation rate from a dry soil surface that was simulated using the coupled model followed the diurnal dynamics of the evaporation from a wet soil surface. Such a dynamics cannot be reproduced by the Richards model that predicts a monotonic decrease in evaporation rate from a dry soil surface. Using a parameterisation that enhances thermal vapour fluxes led to a reduction of evaporation in the afternoon when thermal gradients are directed downward and to simulated evaporation peaks in the morning and evening. Evaporation rates measured from a bare soil using eddy covariance, which provide information about the diurnal dynamics of evaporation rates, will be used to evaluate the different parameterisations of vapour diffusion.