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Geophysical Research Abstracts
Vol. 16, EGU2014-1808, 2014
EGU General Assembly 2014

Physically Accurate Soil Freeze-Thaw Processes in a Global Land Surface Scheme

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Transfer of energy and moisture in frozen soil, and hence the active layer depth, are strongly influenced by the soil freezing curve which specifies liquid moisture content as a function of temperature. However, the curve is typically not represented in global land surface models, with less physically-based approximations being used instead. In this work, we develop a physically accurate model of soil freeze-thaw processes, suitable for use in a global land surface scheme.

We incorporated soil freeze-thaw processes into an existing detailed model for the transfer of heat, liquid water and water vapor in soils, including isotope diagnostics – Soil-Litter-Iso (SLI, Haverd & Cuntz 2010), which has been used successfully for water and carbon balances of the Australian continent (Haverd *et al.* 2013). A unique feature of SLI is that fluxes of energy and moisture are coupled using a single system of linear equations. The extension to include freeze-thaw processes and snow maintains this elegant coupling, requiring only coefficients in the linear equations to be modified. No impedance factor for hydraulic conductivity is needed because of the formulation by matric flux potential rather than pressure head. Iterations are avoided which results in the same computational speed as without freezing. The extended model is evaluated extensively in stand-alone mode (against theoretical predictions, lab experiments and field data) and as part of the CABLE global land surface scheme.

SLI accurately solves the classical Stefan problem of a homogeneous medium undergoing a phase change. The model also accurately reproduces the freezing front, which is observed in laboratory experiments (Hansson *et al.* 2004). SLI was further tested against observations at a permafrost site in Tibet (Weismüller *et al.* 2011). It reproduces seasonal thawing and freezing of the active layer to within 3 K of the observed soil temperature and to within 10% of the observed volumetric liquid soil moisture. Model-data fusion suggests that model performance is improved when the relatively high thermal conductivity of the ice phase is accounted for. However, the permafrost site is very gravelly so that the model equations for thermal conductivity are at the edge of applicability. The freezing-soil formulation is tested in the presence of snow, using measurements at an orchard site in Idaho. The model reproduces well observed snow-water equivalents and soil temperatures. However, it is highly sensitive to snow emissivity and maximum liquid content of the snow, leading both to modified refreezing of melted water. It is possible that the model would benefit from 1-2 more snow layers to permit simulation of density and temperature gradients in the snow-pack.

SLI was run globally on 1°x1° grid as the soil part of the land surface scheme CABLE. We could therefore demonstrate that this detailed and physically-realistic formulation is fast enough to be a feasible alternative to the much simpler default soil-scheme in CABLE.

References

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