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A groundwater and runoff formulation for weather and climate models

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Soil moisture modifies the state of the atmosphere and thus plays a major role in the climate system. Its spatial distribution is strongly modulated by the underlying orography. Yet, the vertical transport of soil-water and especially the generation of groundwater runoff at the bottom of the soil column are currently treated in a crude way in most atmospheric and climate models. This potentially leads to large biases in near-surface temperatures during mid-latitude summertime conditions, when the soils may dry out. Here we present a modified formulation for groundwater runoff formation. It is based on Richards equation, allows for saturated aquifers, includes a slope-dependent groundwater discharge, and enables a subgrid-scale treatment of the underlying orography. The proposed numerical implementation ensures a physically consistent treatment of the water-fluxes in the soil column, using ideas from flux-corrected transport methodologies. An implementation of this formulation into TERRA_ML, the land-surface model of the regional climate model COSMO-CLM, is validated both in idealized and real-case simulations. Idealized simulations demonstrate the important role of the lower boundary condition at the bottom of the soil column, display a physically meaningful recharge and discharge of the saturated zone, and exhibit a closed water budget. Validation against measurements at selected stations show an improved soil-water content. Finally, decade-long climate simulations over Europe exhibit a more realistic representation of the groundwater distribution across continental scales and mountainous areas, an improved annual cycle of surface latent heat fluxes, and as a consequence reductions of long-standing biases in near-surface temperatures in semi-arid regions.