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Anthropogenic soil erosion over the Holocene: Application of a new dynamic soils module for global vegetation models

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Over the course of the Holocene, anthropogenic activities have transformed the surface of the Earth. In no way has human impact been more important or longer lasting than the transformation of soils, where erosion and sediment transport over the past 10,000 years have led to irreversible changes in landscapes. Soil erosion also affected global carbon and nutrient cycles, and could have amplified or attenuated ongoing changes in the Earth's climate. To quantify the role of anthropogenically induced soil development and erosion in the Earth system, we developed a new module of global soil dynamics: soil formation, erosion, and sediment transport, that is suitable for global application at 0.5° resolution. We incorporated this soil module into the LPJ-DGVM and performed a series of simulations to quantify the spatial and temporal pattern of global soil change over the Holocene.

The soil formation module models bedrock-to-soil conversion rates as exponentially decreasing with soil depth. Parameters for soil formation in different geological units were extracted from a review of existing literature. Our global soil erosion formulation is based on the Revised Universal Soil Loss Equation (RUSLE), but importantly accounts for sediment deposition and the net export of sediment out of a relatively large and geomorphologically heterogeneous gridcell. Our new module was developed by running the detailed soil erosion-deposition model WaTEM/SEDEM at 3 arc-second resolution to derive generalized topographical scaling relations that accurately represent hillslope length, slope gradient and sediment delivery ratio. We show that, at large spatial scale, sediment delivery ratio and the area affected by sediment deposition can be easily estimated from topographical parameters such as mean LS factor and wetness index. We include the feedback between soil formation and soil erosion by adjusting the soil erosion rates for soil depth and stoniness.

The results of our Holocene-long simulations indicate that millennia of human impact, mainly deforestation and cultivation, led to exhaustion of soil resources in many parts of the world. In particular, the eastern and southern Mediterranean, the northern Andes, and southern China were strongly affected by anthropogenic soil erosion. Some areas experienced declining rates of soil loss already in the early first millennium CE because of total removal of the soil column. Cumulative carbon emissions to the atmosphere over the Holocene as a result of anthropogenic soil erosion could have approached 200 Pg. Remote sensing-based global maps of topography, soils, and bedrock geology that have recently become available are a valuable resource that will improve our ability to model soil dynamics for the past and future.