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Averaging over spatial heterogeneity leads to overestimation of ET in large scale Earth system models

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Hydrologic processes are heterogeneous at far smaller spatial scales than a typical Earth system model grid (1-5 degree, ∼100-500km). Thus, estimates of evapotranspiration (ET) in most Earth system models average over considerable sub-grid heterogeneity in land surface properties, precipitation (P), and potential evapotranspiration (PET). This spatial averaging could potentially bias ET estimates, due to the nonlinearities in the underlying relationships. Here we estimate the effects of spatial heterogeneity on grid-cell-averaged ET, as seen from the atmosphere over heterogeneous landscapes at global scale. Using a Budyko framework to express ET as a function of P and PET, we quantify how sub-grid heterogeneity affects average ET at the scale of typical Earth system model grid cells (1º by 1º). We show that averaging over sub-grid heterogeneity in P and PET, as typical Earth system models do, leads to overestimation of average ET. Our analysis at global scale shows that the effects of sub-grid heterogeneity will be most pronounced in steep mountainous areas where the topographic gradient is high and where P is inversely correlated with PET across the landscape. This approach yields a simple conceptual framework and mathematical expressions for determining whether, and how much, spatial heterogeneity can affect regional ET fluxes as seen from the atmosphere. Correcting for this overestimation of ET in Earth system models will be important for future temperature predictions, since smaller values of ET imply greater sensible heat fluxes, thus potentially amplifying dry and warm conditions in the context of climate change. This work presented here provides the basis for translating the quantified heterogeneity bias into correction factors for large scale Earth system models, which will be the focus of future work.