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A Budyko framework for estimating how lateral redistribution affects large-scale evapotranspiration

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Most earth system models are based on grid-averaged soil columns that do not communicate with one another, and that average over considerable sub-grid heterogeneity in land surface properties, precipitation (P), and potential evapotranspiration (PET). These models typically ignore topographically driven lateral redistribution of water (either as groundwater or surface flows), both within and between model grid cells. Lateral redistribution may alter not only local evapotranspiration (ET) fluxes, but also regional average ET as seen from the atmosphere over heterogeneous landscapes. For example, if water is laterally transferred from a source location with high precipitation (but low PET) to a recipient location with low precipitation (but high PET), the resulting ET increase in the recipient location may more than offset the ET reduction in the source location. In this example the regional average ET flux, as viewed from the atmosphere, would be increased by lateral redistribution.

The earth system modeling community has recognized the need to account for lateral redistribution of water and its effects on evapotranspiration rates, and our work represents a first attempt to quantify these effects. Our approach uses simple Budyko curves to estimate ET as a function of atmospheric forcing by P and PET. From these curves, we derive a simple criterion for determining whether lateral redistribution will increase or decrease regional average ET, as seen from the atmosphere. Using only estimates of P and PET in the source and recipient locations, we derive expressions for the maximum possible effect of redistribution on regional ET, and the amount of lateral redistribution required to achieve this effect. We likewise derive a dimensionless ratio that quantifies the change in ET per unit of lateral redistribution, again as a function of P and PET in the source and recipient locations.

This approach yields a simple conceptual framework for determining whether, and how much, lateral redistribution can alter regional ET fluxes. Using this approach, one can obtain a first-order estimate for how much lateral redistribution may affect evapotranspiration rates at regional, continental, and global scales.