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Inferring dominant controls on transpiration across a hillslope transect from ecohydrological measurements and thermodynamic limits

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We combine ecohydrological observations of sapflow and soil moisture-derived root water uptake with a thermodynamically constrained estimate of atmospheric evaporative demand to infer the dominant controls on forest transpiration in complex terrain. Specifically we hypothesize that short term variability is dominated by land-atmosphere interaction, whereas site-specific controls determine the sensitivity of transpiration to atmospheric demand.

To explore topographic controls on forest transpiration we use data from a extensive ecohydrological measurement setup which was established within the CAOS (Catchments As Organized Systems) research unit. Specifically, we use data of 5 sites along a steep hillslope transect (15 - 22°) in a deciduous beech forest in Luxembourg. Two sites are located at the north-facing slope, three at the opposite south-facing slope. Each site was equipped with soil moisture sensors at three depths in three profiles as well as heat-pulse sap flow sensors in four trees per site. Meteorological observations (solar radiation, temperature, humidity) are recorded at a nearby pasture.

Both sapflow and soil moisture-derived root water uptake allow for an independent assessment of site-scale transpiration. Although each method has specific limitations, there is a robust relation across sites. This relationship can be used to estimate site scale growing season transpiration. Atmospheric evaporative demand is estimated through thermodynamically constrained evaporation which only requires absorbed solar radiation and temperature as input data and thus allows prediction of evaporative demand independent of surface conditions. The joint analysis of daily data shows that sapflow is highly linearly correlated with atmospheric demand ($r^2 = 0.82$) independent of location, tree size and soil moisture content. Hence the sensitivity of sapflow and root water uptake to atmospheric demand allows for estimating long term controls on transpiration.

Aspect of the hillslopes and stand characteristics were found to be the major long term control: the south-facing sites with larger atmospheric demand show significantly lower sensitivity to atmospheric demand than the north-facing sites. Interestingly, we find that the sensitivity is decreasing with stand density, which is markedly different between the contrasting hillslopes. Thus periodical water limitation induced by larger absorption of solar radiation on the south-facing slopes may have led to long term plant adaptation or forest management strategies which satisfy the trade-off between highly variable atmospheric demand and the depletion of soil water storage.

In summary, the strong linear link of daily transpiration to atmospheric demand as well as the more long-term adaptation to soil moisture availability may allow for the spatially explicit prediction of forest transpiration from solar radiation, temperature and stand characteristics.