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Unravelling spatio-temporal evapotranspiration patterns in topographically complex landscapes

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Vegetation co-evolves with soils and topography under a given long-term climatic forcing. Previous studies demonstrated a strong eco-hydrologic feedback between topography, vegetation and energy and water fluxes. Slope orientation (aspect and gradient) alter the magnitude of incoming solar radiation resulting in larger evaporative losses and less water availability on equator-facing slopes. Furthermore, non-local water inputs from upslope areas potentially contribute to available water at downslope positions. The combined effect of slope orientation and drainage position creates complex spatial patterns in biological productivity and pedogenesis, which in turn alter the local hydrology.

In complex upland landscapes, topographic alteration of incoming radiation can cause substantial aridity index (ratio of potential evapotranspiration to precipitation) variations over small spatial extents. Most of the upland forests in south-east Australia are located in an aridity index (AI) range of 1-2, around the energy limited to water limited boundary, where forested systems are expected to be most sensitive to AI changes.

In this research we aim to improve the fundamental understanding of spatio-temporal evolution of evapotranspiration (ET) patterns in complex terrain, accounting for local topographic effects on system properties (e.g. soil depth, sapwood area, leaf area) and variation in energy and water exchange processes due to slope orientation and drainage position.

Six measurement plots were set-up in a mixed species eucalypt forest on a polar and equatorial-facing hillslope (AI $\sim$1.3 vs. 1.8) at varying drainage position (ridge, mid-slope, gully), while minimizing variations in other factors, e.g. geology and weather patterns. Sap flow, soil water content, incoming solar radiation and throughfall were continuously monitored at field sites spanning a wide range of soil depth (0.5 – >3m), maximum tree heights (17 – 51m) and LAI (1.2 – 4.6).

Site-specific response curves of vapour pressure deficit and sap velocity emerged in relation to landscape position from spring until autumn, while the relationship collapsed into a single curve in winter. These patterns were amplified by more sapwood area per ha in wetter locations compared to drier locations. Topographically downscaled (20x20m pixels) monthly AI values were significantly correlated with monthly observations of sap velocity (R^2 of 0.54 – 0.91) for all landscape positions except the equator-facing ridge position. Moreover, spatial vegetation and sap velocity patterns could be predicted using AI, topographic wetness index and elevation above stream (R^2 of 0.67 and 0.59, respectively).

Our findings emphasise the co-dependence of climate, topography and vegetation, and the need of a more holistic approach that includes terrain and vegetation characteristics to explain ET patterns. Our strong correlations with vegetation patterns and sap velocities demonstrate the potential use of spatially mappable climatic and topographic information to scale ET fluxes in complex terrain, and we anticipate that this approach is applicable across a wide range of ecosystems.