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The role of vegetation optimality in the Budyko-framework

Remko C. Nijzink and Stan Schymanski
Luxembourg Institute of Science and Technology, Environmental Research and Innovation, Catchment and Eco-hydrology Research Group, Belvaux, Luxembourg (remko.nijzink@list.lu)

The Budyko-framework is widely used to assess the water balance of catchments, with large catchments worldwide converging to a constrained set of empirical curves. Ongoing research focuses on explaining deviations of catchments from the Budyko-curve, implying that local characteristics, such as hydrological settings and land use, determine an individual curve for each catchment, along which the catchment travels in response to climatic variability. Here we use vegetation optimality to explain convergence on the Budyko-curve and assess if the Vegetation Optimality Model (VOM, Schymanski et al., 2009) and three conceptual hydrological models support the assumption that catchments follow individual Budyko-curves as climate varies.

The VOM optimizes vegetation properties, such as rooting depths and vegetation cover, for maximum Net Carbon Profit (NCP), i.e. the difference between the total amount of CO_2 assimilated from the atmosphere and the carbon costs for maintenance and respiration of plants. In this sense, the VOM represents vegetation water use as the result of ecological adaptation, while the conceptual hydrological models lump water use into a set of calibration parameters. The following research questions were investigated:

- Does vegetation optimality lead to convergence of catchments on the Budyko-curve?

- Does modelled catchment response to changing precipitation follow a catchment-specific Budyko-curve?

The VOM was applied at five flux tower sites, as well as 36 additional points, along the North Australian Tropical Transect, following a strong precipitation gradient from north to south, and six other catchments in Australia. Beside the VOM, three conceptual hydrological models were applied to the Australian catchments for comparison. In a final step, these hydrological models were run for a selection of catchments in the contiguous United States to generalize the results from Australia.

For each site, the vegetation parameters of the VOM were optimized for maximum NCP, while the conceptual models were calibrated to reproduce observed streamflow. The simulated water balances were used to generate individual Budyko-curves for each site and model run. Subsequently, rainfall was stepwise increased or decreased and the models were re-run to test if each site would stay on its curve. In a second step, the vegetation was re-optimized in the VOM to simulate vegetation response to the new precipitation and the resulting water balance was again

plotted on the Budyko-curve.

The individual Budyko-curves were consistently different for the different precipitation amounts, indicating that modelled responses do not follow a catchment-specific curve. Conversely, if vegetation was re-optimized in the VOM for each rainfall scenario, the different scenarios converged to a single curve for each study site. In other words, adjusting the vegetation to maximize the NCP made the study sites converge back to the initial Budyko-curve. This indicates that convergence onto a Budyko-curve and tracking along a catchment-specific Budyko-curve may not be due to physical constraints, as commonly assumed, but the result of biological adaptation to the environment.

References

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