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The pulse of a montane ecosystem: coupled diurnal cycles in solar flux, snowmelt, evapotranspiration, groundwater, and streamflow at Sagehen Creek (Sierra Nevada, California)

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Forested catchments in the subalpine snow zone provide interesting opportunities to study the interplay between energy and water fluxes under seasonally variable degrees of forcing by transpiration and snowmelt. In such catchments, diurnal cycles in solar flux drive snowmelt and evapotranspiration, which in turn lead to diurnal cycles (with opposing phases) in groundwater levels. These in turn are linked to diurnal cycles in stream stage and discharge, which potentially provide a spatially integrated measure of snowmelt and evapotranspiration rates in the surrounding landscape.

Here I analyze ecohydrological controls on diurnal stream and groundwater fluctuations induced by snowmelt and evapotranspiration (ET) at Sagehen Creek, in the Sierra Nevada mountains of California. There is a clear 6-hour lag between radiation forcing and the stream or groundwater response. This is not a travel-time delay, but instead a 90-degree dynamical phase lag arising from the integro-differential relationship between groundwater storage and recharge, ET, and streamflow. The time derivative of groundwater levels is strongly positively correlated with solar flux during snowmelt periods, reflecting snowmelt recharge to the riparian aquifer during daytime. Conversely, this derivative is strongly negatively correlated with solar flux during snow-free summer months, reflecting transpiration withdrawals from the riparian aquifer. As the snow cover disappears, the correlation between the solar flux and the time derivative of groundwater levels abruptly shifts from positive (snowmelt dominance) to negative (ET dominance). During this transition, the groundwater cycles briefly vanish when the opposing forcings (snowmelt and ET) are of equal magnitude, and thus cancel each other out.

Stream stage fluctuations integrate these relationships over the altitude range of the catchment. Rates of rise and fall in stream stage are positively correlated with solar flux when the whole catchment is snow-covered, and negatively correlated with solar flux when the whole catchment is snow-free. The correlation with solar flux gradually shifts from positive to negative over several weeks, as the snow-covered area contracts higher and higher in the basin. The dates at which the snowmelt and ET signals in the stream cancel each other out occur systematically later at higher altitudes along the stream's longitudinal profile. At these particular dates, it may be possible to infer spatially averaged rates of ET (which are difficult to measure accurately) from spatially averaged rates of snowmelt (which can be estimated somewhat more straightforwardly from energy balance). These observations illustrate how groundwater and stream stage fluctuations are mirrors of the landscape, reflecting the energetics of snowmelt and evapotranspiration at the plot and catchment scale.