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A spatially-distributed assessment of non-stationary green and blue water ages in a pristine tropical rainforest

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A complete understanding of hydrology and solute dynamics of tropical humid catchments requires spatio-temporal tracking of fluxes, storage, mixing and flow paths. Additionally, we lack detailed knowledge about how precipitation is partitioned into distinct "green and blue" hydrological processes and their respective transit and residence times. Particularly in the tropics, vegetation plays an important but often underestimated role in hydrological and biogeochemical cycles. If we want to assess future environmental changes on these cycles, we need a better understanding of "green" water fluxes.
To this end, we further developed the Spatially-distributed Tracer-Aided Rainfall-Runoff for the tropics (STAR-Rtropics) model to simulate rainforest interception, transpiration, soil water and groundwater fluxes, tracing stable water isotopes throughout the model cascade. The quick runoff response of our system slightly below 1 hour demands high-resolution spatial (10 m) and temporal (1 h) simulations to close the gap between the high-frequency hydrometric and fewer isotope sampling.
Data collection within our pristine rainforest experimental catchment (San Lorencito 3.2 km2) in Costa Rica was carried out from Jun 2013 to May 2018. Hydro-meteorological data was registered with 5 min resolution, spatially distributed soil moisture and water samples for isotope analysis were collected on an event-basis if possible, every 15min. Water samples were collected in gross rainfall, throughfall, the main stream and two tributaries.
The model was able to reproduce the observed streamflow very well (KGE > 0.8). The average annual streamflow was mostly composed of shallow soil water components (∼90%) and the remnant by water from deeper layers. From the total evapotranspiration, the isotope mass balance showed that up to 80% is transpired water. Although this is not surprising in the rainforest ecosystem with high relative humidity above 90% throughout the year and a mostly cloudy sky. Isotope simulations showed a "flashy" response to rainfall in combination with a nearly constant isotope signature from deeper groundwater during baseflow.
Simulated stream water age distributions ranged from hours to two years with little older water contributions supporting the notion of a quick responding system with low potential for resilience after more severe changes of the hydrological cycle and precipitation patterns. The water age distributions of interception and transpiration fluxes (hours-weeks) were significantly lower than those of the stream. The stream water ages were a mixture of younger soil (hours-months) and older groundwaters (months-years). Spatially, we detected minor but not negligible age differences between waters originating on the right (old) compared to the left (young) hillslopes of our V-form river valley. Such spatial differences can be directly attributed to a slightly lower slope and resulting deeper soils on the right-hand hillslope.
This study shows the value of a high-resolution spatially distributed tracer-aided model with a robust database allowing multi-criteria evaluation of simulations to produce an internally consistent representation of the study catchment. The application of the model helped us to improve our understanding of the hydrological functioning, particularly in terms of temporally and spatially non-stationary water ages in a geomorphologically and biologically complex humid tropical ecosystem.