Visualisation of spatial patterns of connectivity and runoff ages derived from a tracer-aided model

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Description

Mixing relationships between fluxes and storages in a catchment can be investigated with hydrological models that include conservative tracers, e.g. stable isotopes (Birkel and Soulsby, 2015). That way, the evolution of water ages in relation to flow path dynamics can also be investigated (Birkel et al., 2015; Hrachowitz et al., 2013; McMillan et al., 2012). Here, we present a visualisation of the results from a spatially distributed tracer-aided rainfall-runoff (STARR) model that combines the simulation of hydrometric variables with the simulation of stable isotopes dynamics and tracks the water age (full details are given by Van Huijgevoort et al., 2016). The aim of this visualisation is to show the catchment scale fluxes and water ages over the seasonal extremes of wetness and dryness for a Scottish catchment, in particular demonstrating novel insights into the dynamics of connectivity and consequent spatial interactions of the water age across the catchment.

The STARR model integrates the general hydrological structure of the HBV-light runoff model (Lindström et al., 1997; Seibert and Vis, 2012) with a parameterisation of tracer mixing and flux tracking. It consists of a soil store and groundwater store that are conceptualized as linear reservoirs; all runoff fluxes from each grid cell are routed through the catchment to simulate discharge. The model was developed for an experimental site in the Scottish Highlands, the Bruntland Burn (BB) catchment, but the aim was to keep the model simple in order to derive a generic model that can be applied across regions (Tetzlaff et al., 2015). The BB (3.2 km^2) has a mean annual precipitation and discharge of ~1000 mm and ~600 mm, respectively (Geris et al., 2015; Tetzlaff et al., 2014). Two major landscape units can be distinguished: the wide flat valley bottom, which is dominated by peat soils (histosols) and steeper hill slopes, which are characterised by more freely draining podzols that support groundwater recharge. The valley bottom includes an extended riparian zone with a quasi-permanently saturated area, which has a significant influence on runoff generation (Birkel et al., 2011). Time series of daily discharge, precipitation and potential evapotranspiration were available for the catchment, as well as a unique long-term data set of daily time series for stable isotopes for the stream and precipitation.

The STARR model was run on a 100 by 100 m resolution grid for the BB for a 4 year period. It was calibrated for 9 parameters using a dual calibration criterion that takes into account both the discharge and the isotope ratios at the outlet. Soil parameters have different values for the two major landscape units (valley bottom and the hill slopes) to represent the importance of the saturated area within the valley bottom area (Van Huijgevoort et al., 2016). To estimate the water ages and isotope ratios, a complete, instantaneous mixing of the inputs was assumed according to dynamic and passive storage volumes, and the ages of the water stores were tracked in a spatially-distributed way on a daily time step providing partial mixing at the catchment scale. Here, the term water age refers to the water age that was tracked in the model to avoid the ambiguity of travel times and residence times.

This visualisation shows the simulated spatial distribution of total runoff from each grid cell (left panel) and age of the runoff (right panel) across the catchment for the year 2013 to provide novel insights into the connectivity and water age dynamics. Total runoff refers to the sum of all runoff values for each cell (surface runoff and subsurface runoff from the soil and groundwater stores). The top part of the visualisation shows an aerial photo of the catchment and the time series of the observed discharge at the outlet and observed precipitation. To show the differences between the valley bottom and hill slopes over time, the scales in the animation are based on percentile values of the simulated values over the catchment with each class representing a 5th percentile value. In the spatially distributed plots, runoff (left panel) from the hill slopes was lower than the runoff from the valley bottom (central part of the catchment) during the whole year. This correlated with the simulated storage values, which were higher in the valley bottom (not shown here). As a result, the water ages of the runoff (right panel) were also different between valley bottom and hill slopes. Oldest water (~3 years) was found in the valley bottom and younger water (~ a few months) on the hill slopes. Both the spatial distribution of the runoff and associated water ages showed the importance of the riparian area for the mixing of the water at the catchment scale. The larger amount of water in the riparian area led to older water compared to the hill slopes.

The summer of 2013 (June to September) was quite extreme for Scotland and was the warmest and driest period for over 10 years (Geris et al., 2015). During this dry period, the cells of the hill slopes disappear (around the end of July, time 00:40). This means that the hill slopes were completely disconnected from the valley bottom for a short period. During the dry period the water became older in both the valley bottom and the hill slopes; the increase in water age spread from the valley bottom upwards towards the upper hill slopes (red colours). The large reservoir of drift storage in the valley bottom dominated low flow fluxes and the water age in the valley bottom during the dry period (time 00:44 until 00:56).

After the dry summer (from 00:56 onwards), the runoff (left panel) seemed to recover quickly, mainly due to the wetter winter, whereas it took longer for the ages (right panel) to recover. The influence of the increased flux of younger hill slope water under wet conditions in decreasing water ages in the valley bottom became apparent though. The fluxes from areas of low storage uphill were able to overwhelm the storage with older water in the valley bottom with younger water during large runoff events (from 01:09).

Here, we visualise the dominant influence of storage in the valley bottom on runoff fluxes and water ages in the BB. The water in the valley bottom is always older than the hill slopes although the increased flux of younger water during high runoff events is visible in the water age of the discharge. This approach has wider potential for visualising the spatio-temporal patterns of connectivity at the catchment scale and the implications for water ages. These visualisations could lead to increased knowledge of catchment processes.

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