Reducing uncertainty in streamflow predictions using reverse hydrology

The challenge

The modelling of environmental processes is subject to a high degree of uncertainty due to the presence of random errors and a lack of knowledge about how physical processes operate at the scale of interest.

Use of uncertain data when identifying and calibrating a model can result in uncertain parameter estimation and ambiguity in the outcomes. Rainfall-runoff modelling, where a single rain-gauge is often assumed to be representative of the potentially highly variable (in both space and time) rainfall field, is a good example. Instead, we apply a novel method for inferring 'true' catchment rainfall from streamflow (so-called 'reverse hydrology'), highlighting that streamflow is better estimated using inferred rainfall than observed rainfall (from a single gauge) because a single gauge gives only a partial description of the rainfall field.

What was achieved

Reverse hydrology utilises the information in the streamflow exiting the catchment to infer the rain that has fallen over the whole catchment rather than the amount measured at an individual rain gauge. The latter may not be representative of the total rainfall field and may even lead to spurious spikes in the modelled flow where rain has been measured at the gauge but not elsewhere in the catchment. This technique could deliver an improved estimate of the total rainfall. Indeed, reverse hydrology could be an important tool in developing our understanding of catchment rainfall distribution, and the processes by which it is converted into streamflow, leading to a reduction in uncertainty and an improvement of future flow predictions that might result in saved lives, reduced damage to property and infrastructure, and ultimately to decreased costs.

How we did it

Models were identified using the observed rainfall series for individual gauges drawn from a set of 23 gauges and the catchment outflow. The model was then inverted using the regularisation method. In order to compare the inferred and observed rainfall sequences and determine the time resolution of the inferred sequence, aggregation by sub-sampling at increasing sampling intervals was performed. Nash-Sutcliffe Efficiency (R_t^2) was calculated at each interval, and the time interval with the closest fit to the observed (aggregated) rainfall (highest R_t^2) was taken to be the time resolution of the inferred rainfall. The R_t^2 of the aggregated sequence was compared with the R_t^2 of the fitted indicating that, despite the loss of time-resolution, the results are closely comparable. For all gauges, the aggregation period (estimate of time resolution) of the inferred rainfall sequence is less than the value of the model's fast time constant, implying that the catchment dynamics are being captured. Flow was generated using the inferred rainfall sequence from each individual gauge. The resulting flow sequences were found to more closely match the observed flow (typically $R_t^2 = 0.996$) than flows generated from models fitted to individual gauges ($R_t^2 = 0.804$ to 0.831) or flow generated from a model fitted using the catchment average rainfall calculated from 23 gauges using the Thiessen Polygon method ($R_t^2 = 0.852$).

References

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