Modeling the Spatiotemporal Dynamics of Stream Temperature in a Mixed-Use Farmland Catchment

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Introduction

Temperature is an important variable that controls biogeochemical processes in aquatic systems. Complex interactions between land surface - subsurface processes make accurate simulation of stream temperature dynamics a challenging task. This work provides a watershed-scale framework to model stream, soil, streambed and groundwater temperatures coupled with hydrologic and vegetation processes in a mixed land use catchment at the BIFOR facility. The availability of high-resolution stream flow, temperature, and nutrient data at the BIFOR site provides the motivation for this work.

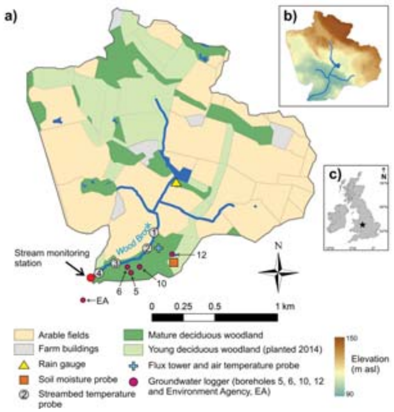

Figure 1. Map of the Mill Brook watershed in the BIFOR facility showing locations where data were collected.

Methods

- We developed a temperature module for the PAWS model (Process-based Adaptive Watershed model; Shen and Phanikumar, Adv. Water Resources, 33, 1524–1541, 2010; Shen et al., Water Ressour. Res., 49, 2552–2572, 2013) and applied it to the Mill Brook watershed at the BIFOR facility of the University of Birmingham.
- PAWS Simulates key hydrologic processes including surface and subsurface flow, channel flow, topography-induced overland flow, vegetation growth processes, soil water processes and the surface energy balance. We used 20 m x 20 m Cartesian grids with 22 vertical layers to represent the vadose zone and the fully-saturated groundwater domains. A time step of 5 minutes is used for the simulations. Climate forcing: hourly precipitation, air temperature, dew point temperature, cloud cover and average wind speed
- We used a one-dimensional (1D in the direction of flow) stream temperature model based on a full energy balance coupled to a one-dimensional streambed temperature equation which in turn is coupled to a two-dimensional "deep groundwater" temperature equation. The 2D groundwater temperature model provided a better description of borehole temperature data compared to the mean air temperature which is often used to approximate groundwater temperature.

Results

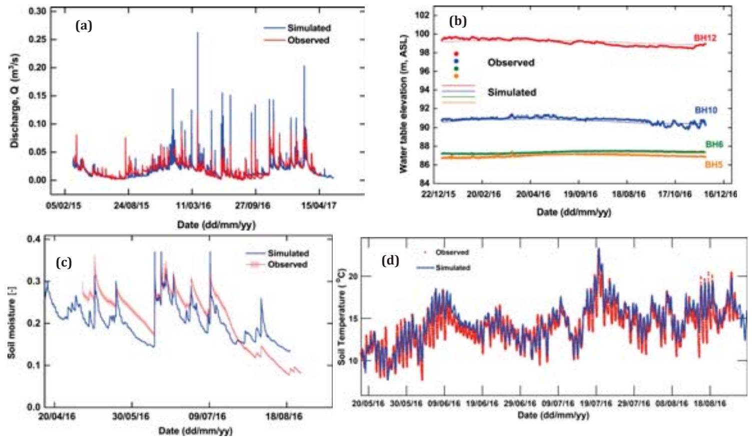

Figure 2. Comparisons of observed versus simulated (a) streamflow at the basin outlet (b) water table elevations in the unconfined aquifer (c) soil moisture and (d) soil temperature.

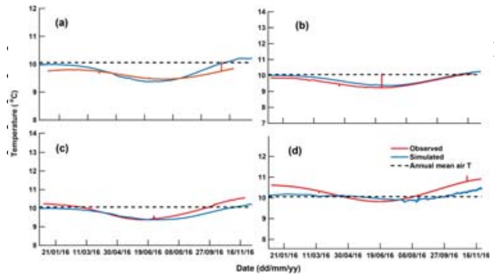

Figure 3. Observed versus simulated groundwater temperature compared with mean annual air temperature.

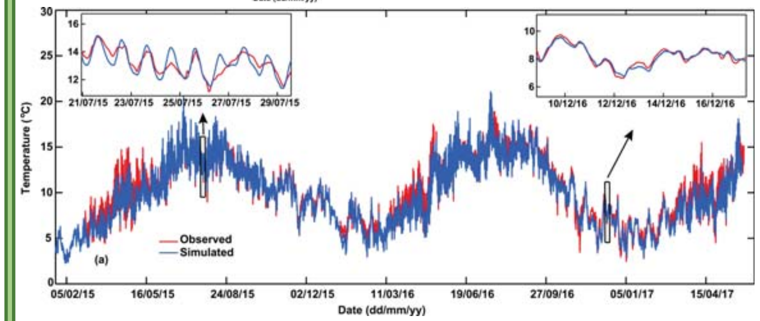

Figure 4. Comparison of observed and simulated stream temperature as a function of time. A 1:1 plot of the same data is shown in Figure 5.

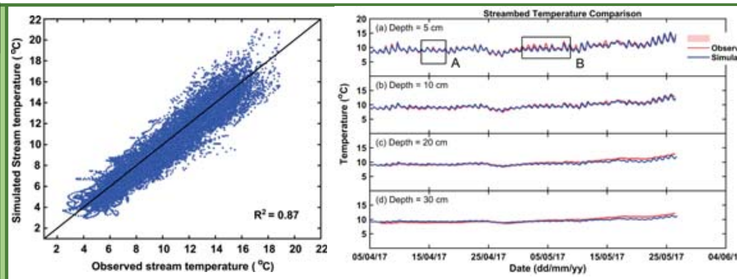

Figure 5. (Left panel) Stream temperature (Right panel) Comparison of observed and simulated streambed temperature at Site 1 (marked in Figure 1). The uncertainty in temperature measurement is plotted using a band of light red color around the solid red line which denotes observed data. A close-up view of the regions marked "A" and "B" in the top panel is shown below in Figure 6.

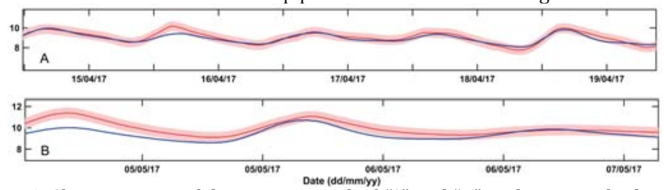

Figure 6. Close-up view of the regions marked "A" and "B" in the streambed temperature comparison from Figure 5.

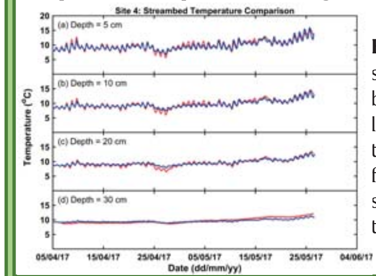

Figure 7. Comparison of observed and simulated streambed temperature near the basin outlet (Site 4 in Figure 1). Similar level of agreement is noted for comparisons at the other sites (sites 2 and 3). The R^2 values for streambed temperature comparisons at all sites and depths are summarized in the table below.

R^2 values	5cm	10cm	20cm	30cm
Site1	0.76	0.77	0.76	0.77
Site2	0.72	0.75	0.79	0.78
Site3	0.73	0.71	0.7	0.71
Site4	0.72	0.72	0.82	0.86

Conclusions

- The Mill Brook watershed and temperature model is able to describe hydrology (stream flows, groundwater heads, soil moisture) as well as stream, soil and groundwater temperatures reasonably well. There is room for improving some of the model inputs (e.g., soil and groundwater domains).

Future Directions

(a) Modeling nutrient dynamics in the Mill Brook watershed by including temperature-dependent reaction rates (b) Detailed analysis of observed and simulated time series to understand hysteresis in concentration/temperature versus discharge

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