What causes cooling water temperature gradients in a forested stream reach?

Grace Garner[1]; Iain A. Malcolm[2]; David M. Hannah[1]; Jonathan P. Sadler[1]

[1]School of Geography, Earth & Environmental Sciences, University of Birmingham, UK
[2] Marine Scotland Science, Freshwater Laboratory, Faskally, Pitlochry, UK

Research context

- Woodland associated with decreases in: diurnal variability, mean and maximum water temperature
- Daytime ‘*cooling gradients*’ observed for reaches shaded by trees downstream of clear cuts and open landuse

Research gaps:

- Existing Studies confounded by cool groundwater inputs
- No explicit conceptualisation of the processes driving cooling patterns in forested reaches without groundwater inputs

Why is this research important?

- Riparian vegetation advocated as climate change mitigation strategy in E.U. and N. America
- Process based understanding informs future riparian strategies to maximise benefits at minimal cost.

Aim and Objectives

AIM:

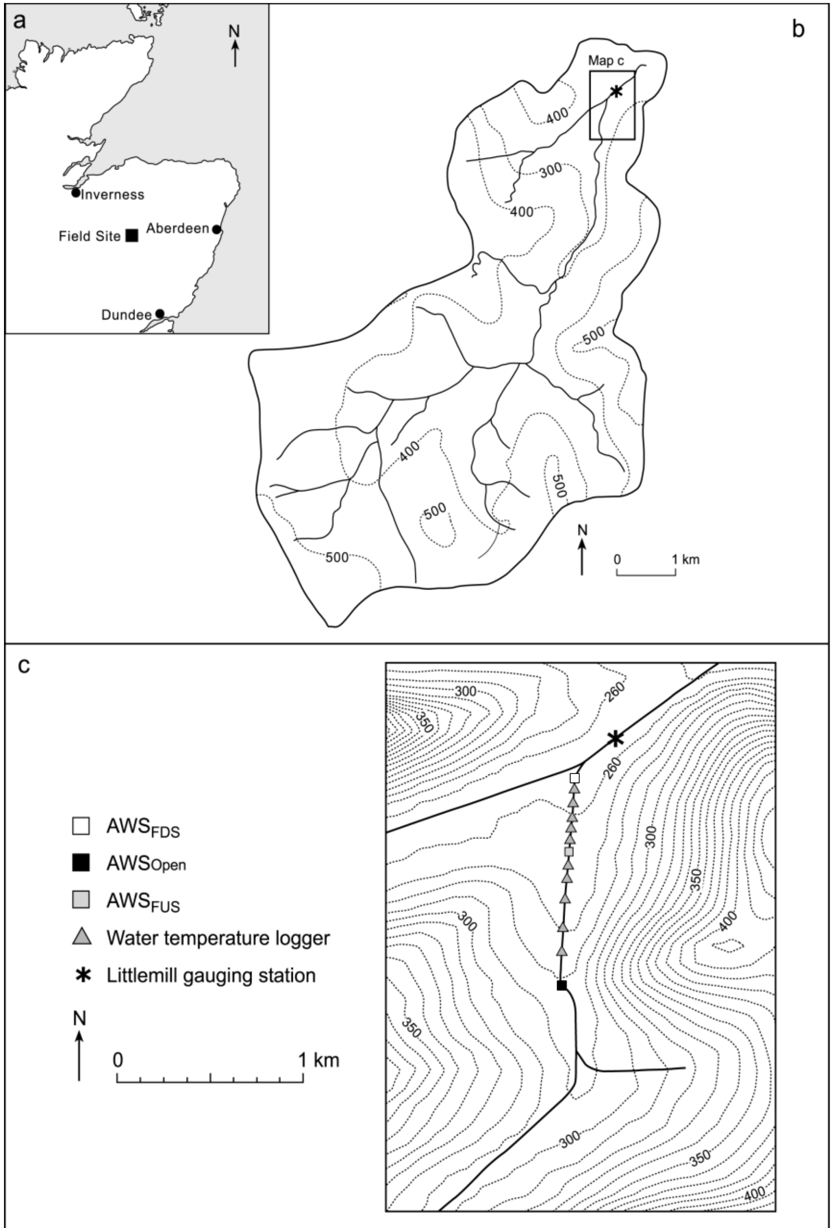
To *quantify* and *model* spatio-temporal variability in stream temperature and heat fluxes for an upland reach that transitions from open moorland to semi-natural woodland

OBJECTIVES:

1. To quantify the magnitude of instantaneous longitudinal temperature gradients within the reach

2. To understand how and why water temperature changes as it travels beneath the forest and attribute to underlying processes

Study area & sites



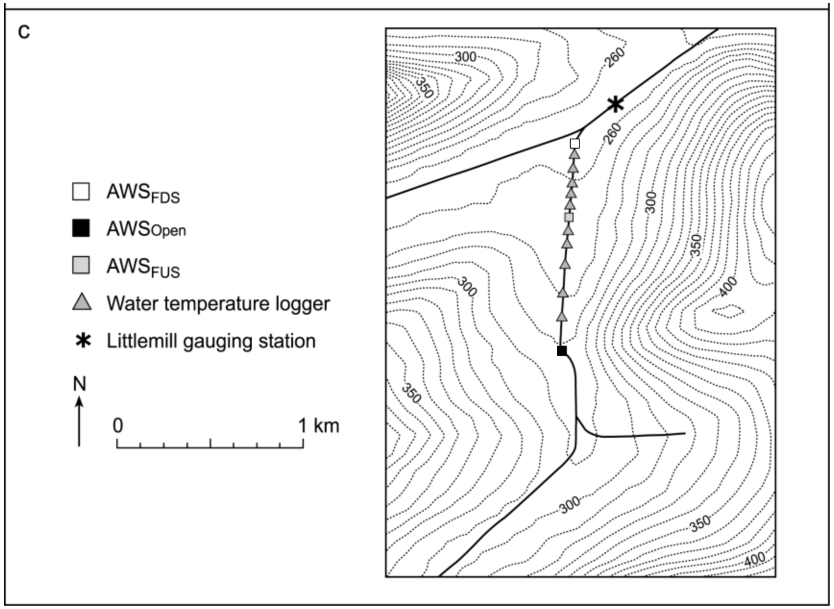
Area:

- Girnock Burn, upland tributary of the Aberdeenshire Dee
- Semi-natural catchment

Reach:

- Established 1050 m study reach
- Upstream (25 km^2) landuse dominated by heather moorland
- Within the reach, landuse transitions from moorland to semi-natural forest

Instrumentation



10 water temperature loggers

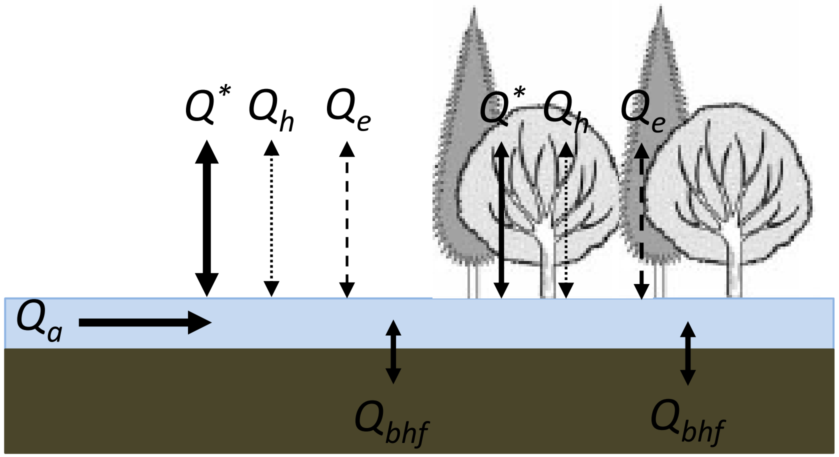
3 automatic weather stations (AWSs) incl. thermistors

211 hemispherical photographs- to scale radiation measurements

Methods

Stream energy budget:

$$Q_n = Q_a + Q^* + Q_e + Q_h + Q_{bhf}$$



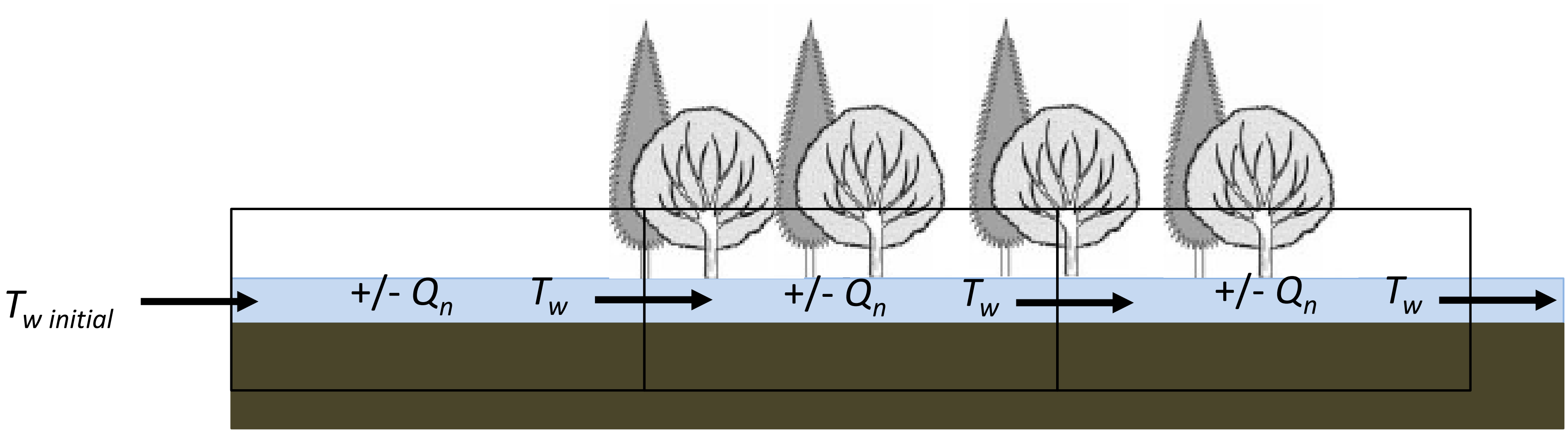
Where:

Q_n = net energy flux
Q_a = longitudinal advected heat flux
Q^* = net radiative flux
Q_e = latent heat flux
Q_h = sensible heat flux
$\mathbf{Q_{bhf}}$ = bed heat flux

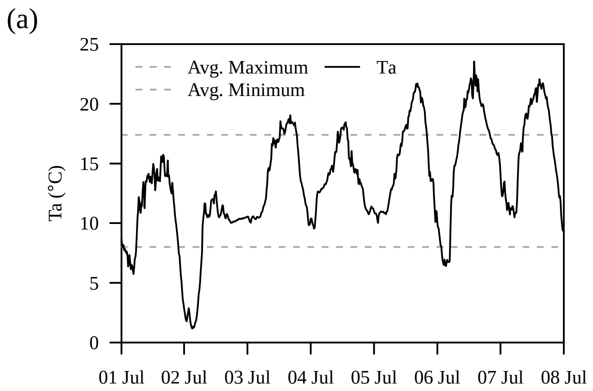
Methods

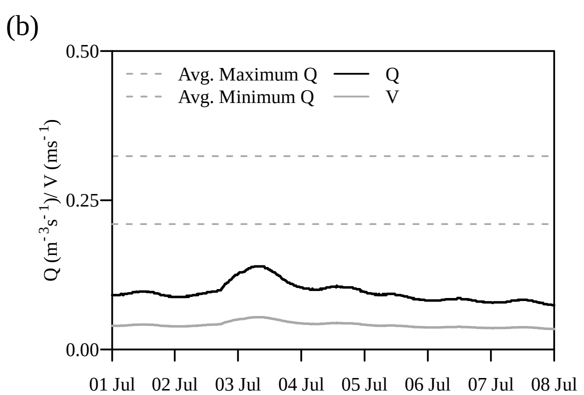
How and why does water change as it moves through the reach?

- Energy flux model incorporating flow routing (i.e Lagrangian model)
- Model simulated change in temperature of water parcels released from upstream reach boundary at 1 m resolution & 15 min. intervals



Results: study period

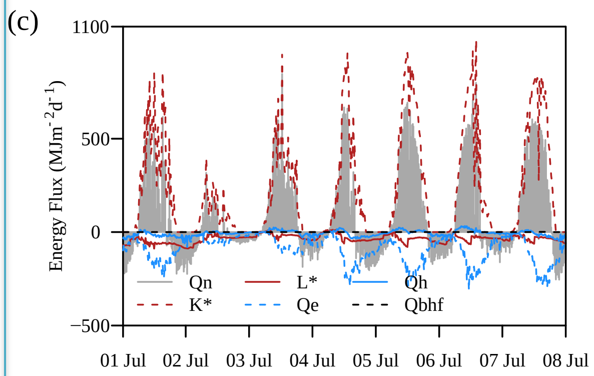




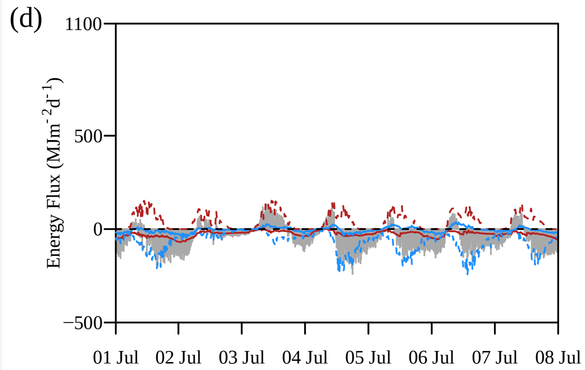
- 7-day study period during summer 2013
- Minimal (4.2 mm) rainfall
- 'Worst-case' scenario of high energy gains & low flows

Results: observed hydrometeorological data

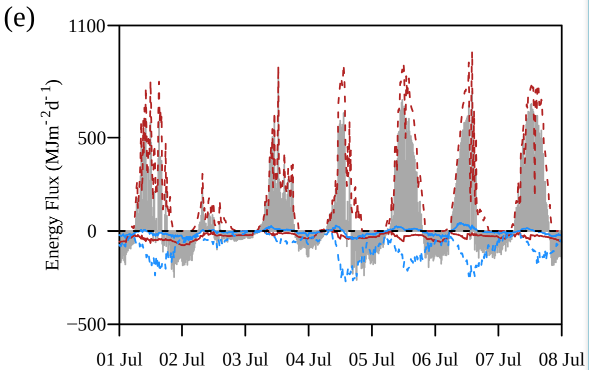
Open site



Forest site 1

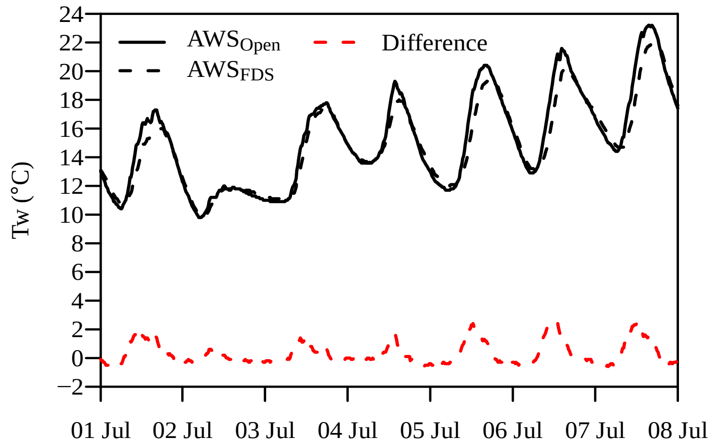


Forest site 2

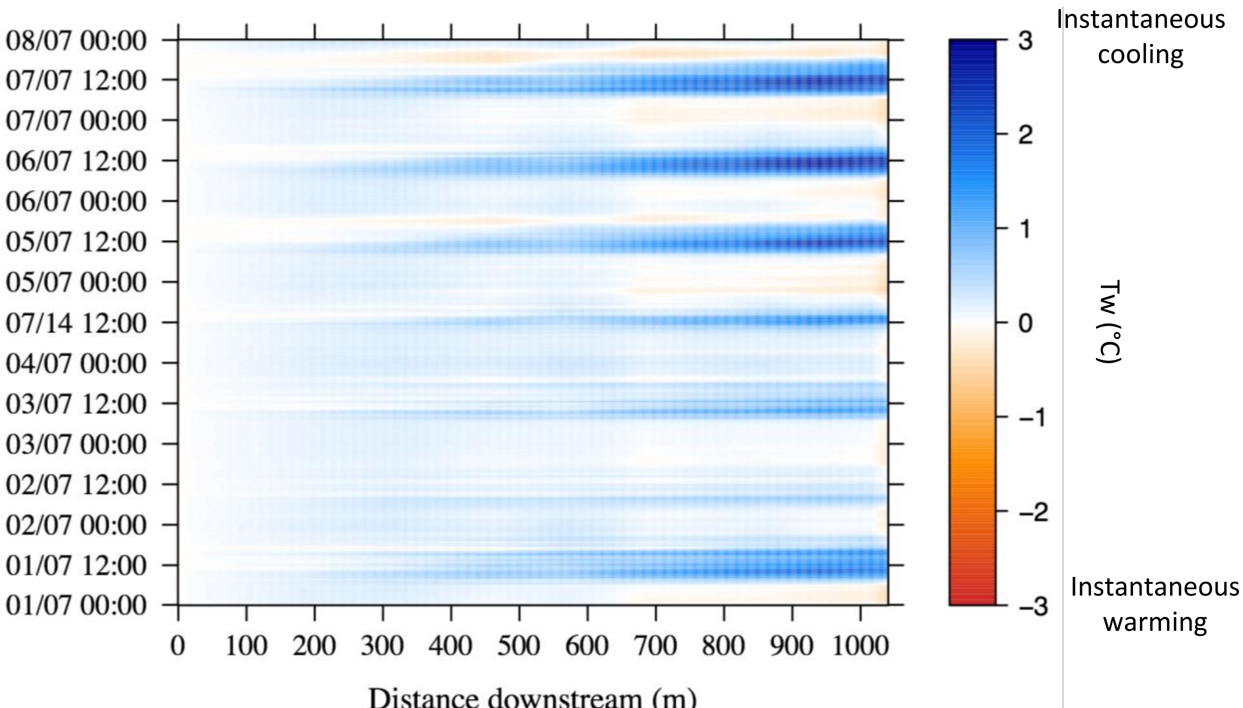


- Energy exchange highly spatially (& temporally) heterogeneous
- Energy exchange at water column-atmosphere interface dominated energy budget (miniscule bed heat flux)

Results: observed spatio-temporal T_w patterns

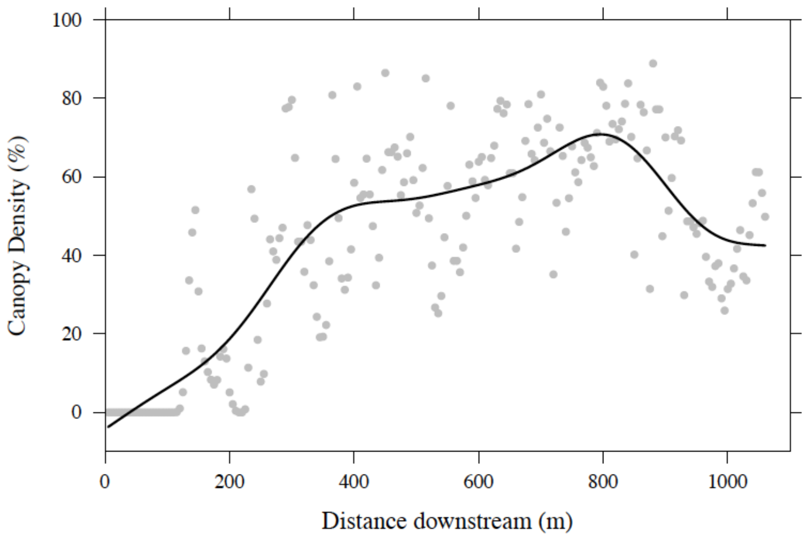


- T_w at upstream reach boundary up to 2.5 °C warmer than downstream boundary
- Minima occur synchronously. Downstream maxima lag upstream by up to 1 hour

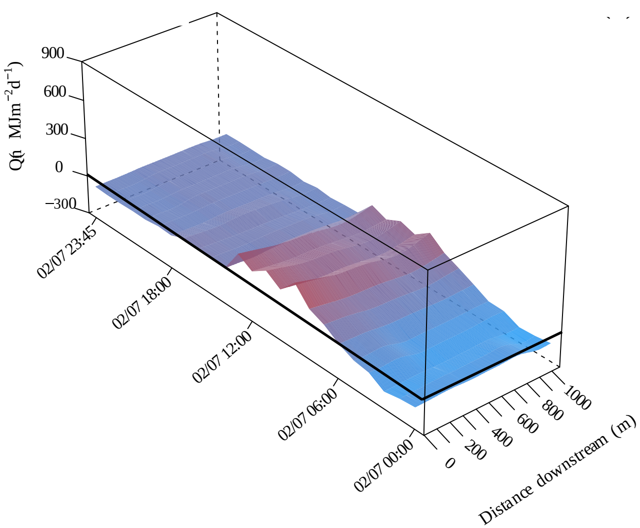


- Instantaneous differences increase with distance downstream

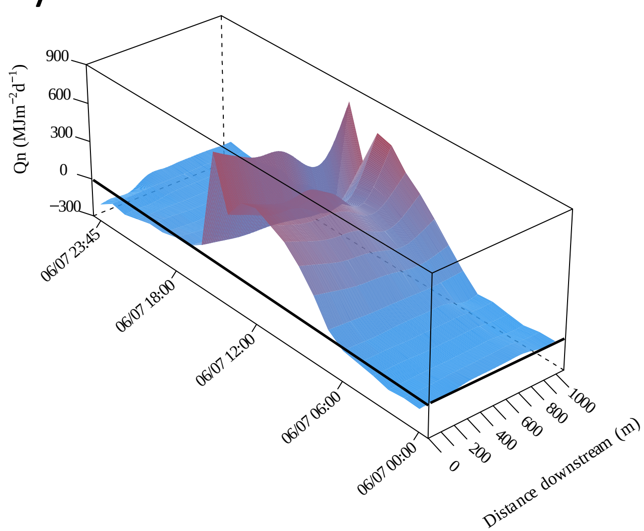
Results: estimated spatio-temporal Q_n patterns



Day two

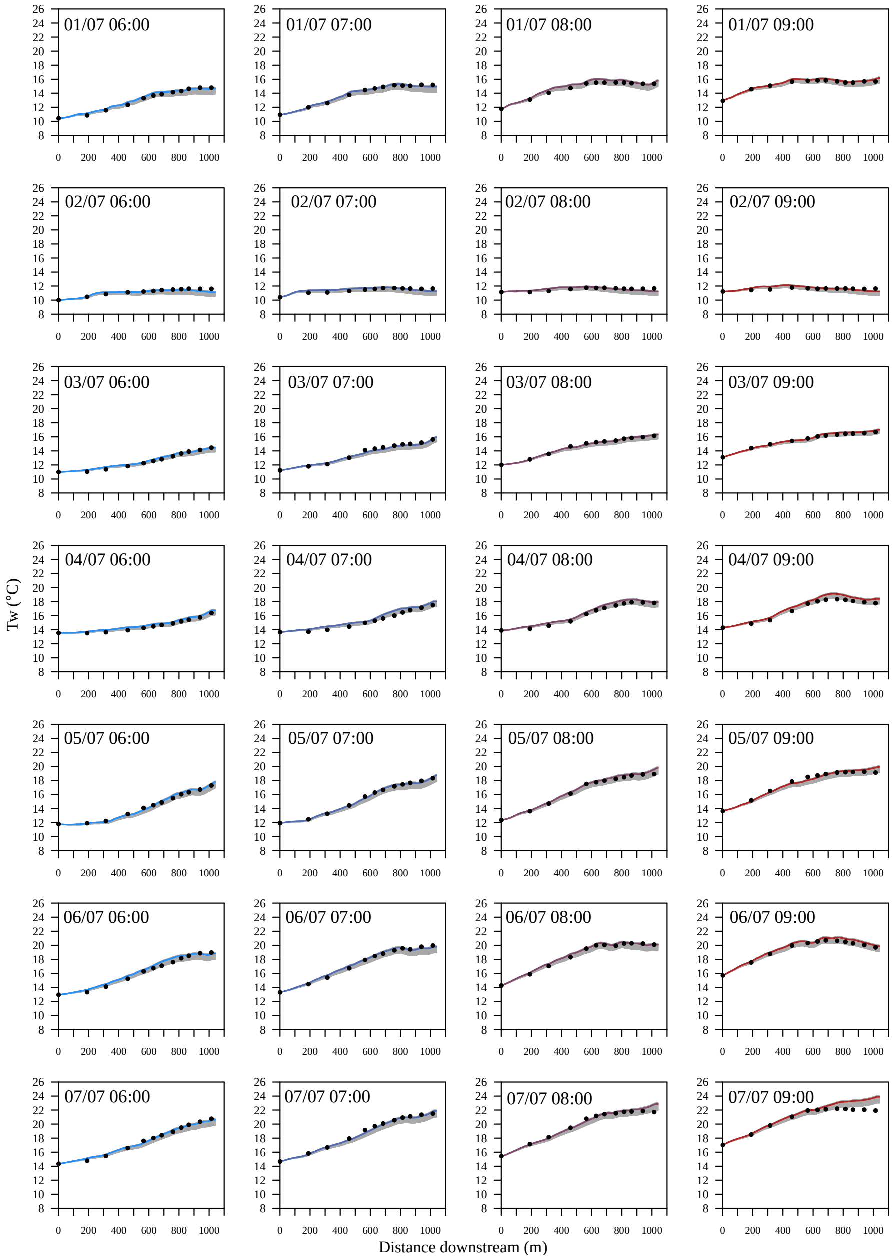


Day six



- Longitudinal patterns of net energy flux correspond broadly to canopy density
- Net energy gains to the stream during daytime
- Net energy losses overnight
- So, how do cooling gradients develop during the daytime if the stream is gaining heat?

Results: T_w model performance



Model performance typically good:

- Bias = <2.0%
- $R^2 = 0.9$
- NSE= 0.95

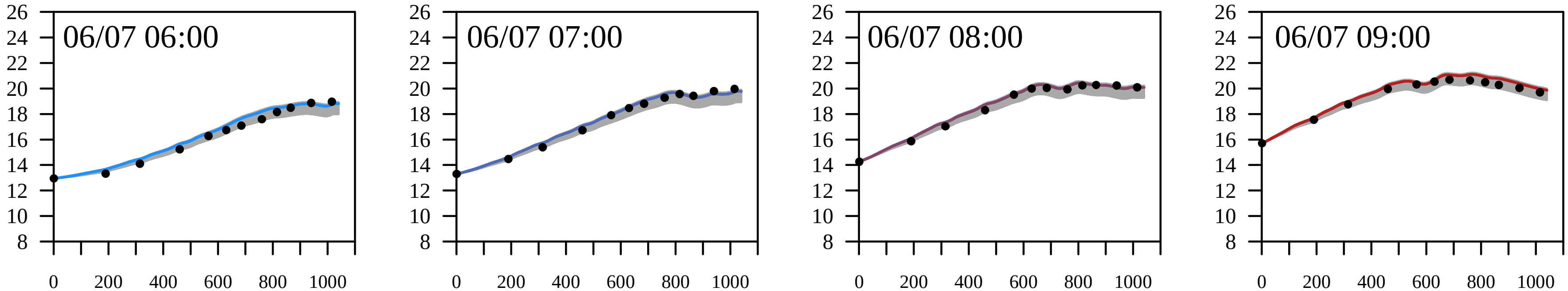
Despite limited representation (only by bed heat flux plates) of potential:

- Lateral groundwater inflows
- Volumes, residence times & temperatures of hyporheic water

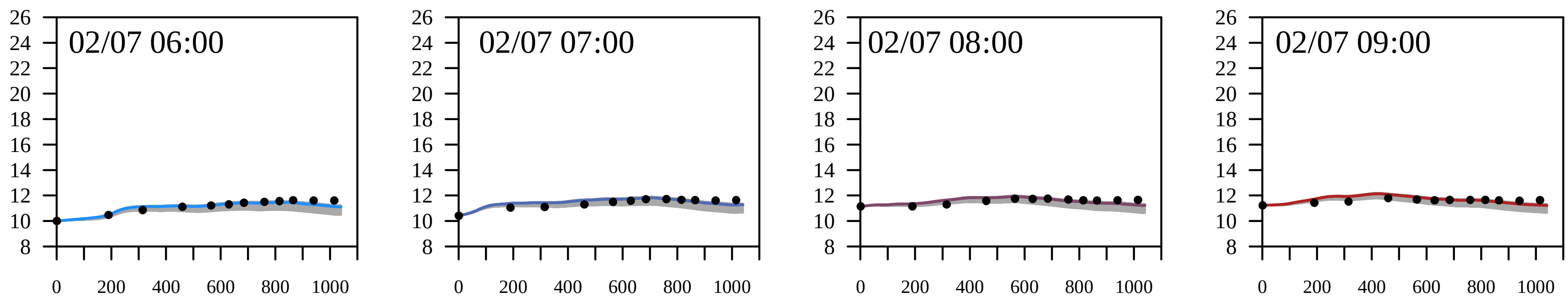
Therefore- confident that patterns driven by surface energy exchages

Results: T_w model

'Water parcels' released at 0 m averaged 6 hrs 30 mins to travel 1050 m



- On days 1 & 3-6 (high energy receipt) parcels released prior to solar noon warmed > 4.2 °C between 0 and 1050 m
- Parcels were cooler on arrival at 1050 m than parcels concurrently at 0 m.



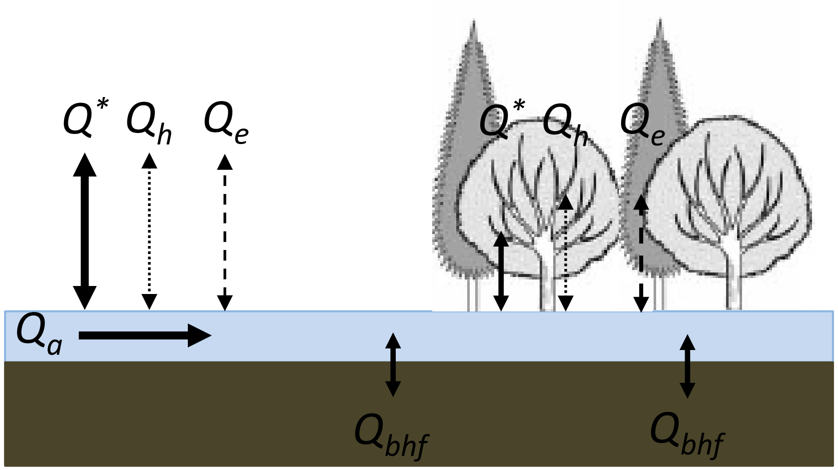
- On day 2 (low energy receipt) parcels released prior to solar noon warmed very little between 0 and 1050 m
- Parcels were the same temperature on arrival at 1050 m as parcels concurrently at 0 m.

Interpretations

What generates instantaneous longitudinal cooling gradients?

1. Dramatically reduced energy gains under the riparian canopy in comparison to open landuse, which reduces the rate at which water temperature increases as it flows downstream.

2. While temperature of water advected into the reach increases over morning.



Conclusions

- Water does not necessarily cool as it flows downstream under semi-natural forest canopy in the presence of energy gain conditions, yet longitudinal gradients may still be generated.

- Energy gains to the water column are reduced dramatically in comparison to open landuse.

- Longitudinal cooling gradients may be generated when temperature of water advected into a reach increases consistently, while temperature increases are minimal under the forest canopy.

Implications

Wish to mitigate against high water temperatures?

- Shade headwaters!
- Where water hasn't warmed to equilibrium with atmosphere and is thus cooler than majority of locations lower in the basin
- Can hypothesise that this will also lower temperatures downstream, by reducing longitudinal advection of heat, and so warming

Acknowledgements

Thank you to:

- Marine Scotland Freshwater Laboratory staff
- Jason Leach & Dan Moore
- NERC
- Anne Anckorn
- Nigel Mottram

We also have a poster on investigating the effects of shading scenarios on reach-scale water temperature dynamics!

Poster 4-2P