Resolving spatiotemporal variation in climate warming of mountain streams using dense sensor arrays and air temperature microclimate models

Air, Water & Aquatics Program

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Introduction

Air temperature increases from global warming are expected to increase temperatures in the Earth's rivers and streams this century. Where long-term monitoring records are available from minimally altered mountain streams (i.e., no urbanization, flow regulation, or recent wildfires), it is often the case that stream temperatures change at slower rates than air temperatures (Figure 1).

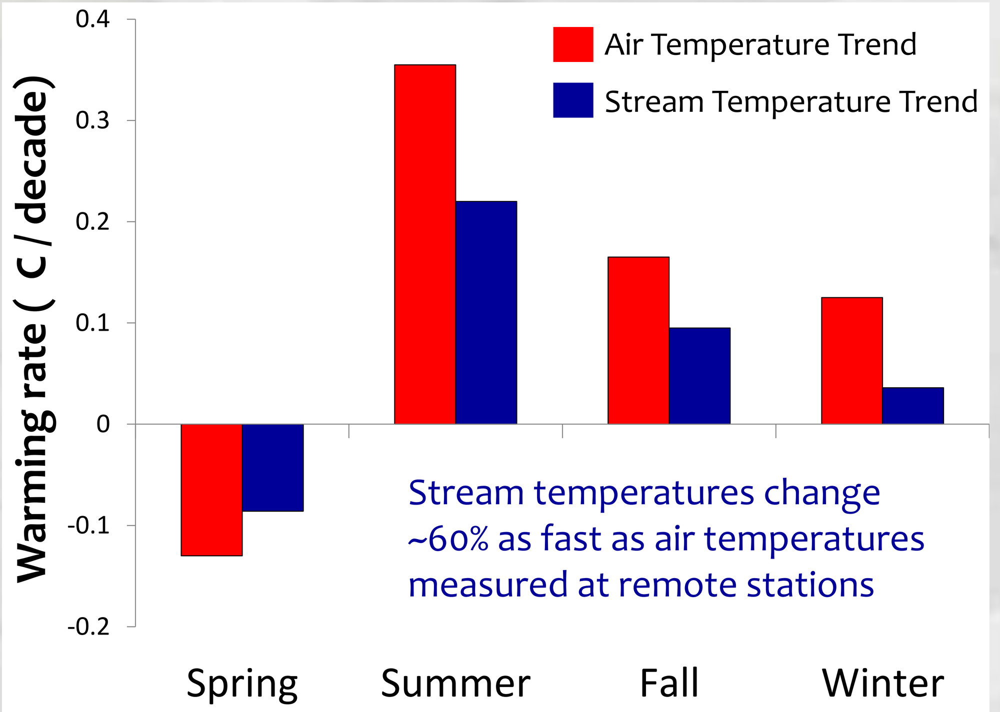
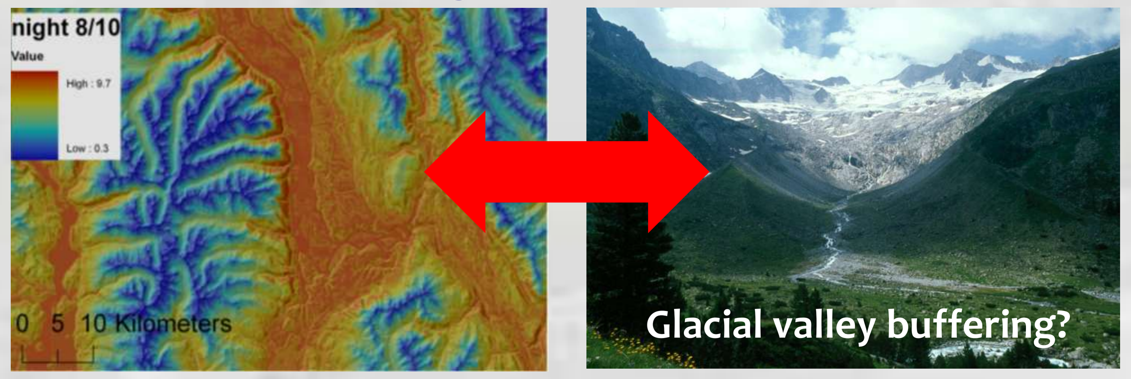


Fig 1. Comparison of 30-year trends (1980-2009) in air and stream temperatures for 7 minimally altered streams across the Northwest U.S. Air temperatures were measured from stations 10 – 100 kilometers away from stream sites; stream temperatures were measured at USGS gages (figure modified from Isaak et al. 2012).

Two hypotheses may explain why stream temperatures change at slower rates than air temperatures. It could be that air temperatures in valley bottoms are partially decoupled from regional climate patterns and change less than ridgeline temperatures or the free-air masses modeled by global and regional climate models (Figure 2a; decoupling hypothesis). Alternatively, it could be that groundwater inputs or other geomorphic/riparian features buffer streams from climate warming and that some streams are more buffered than others (Figure 2b; differential sensitivity hypothesis).

Fig 2. Different air temperature forcing? (a) Different sensitivity? (b)



Data Collection

Precise, local air and stream temperature measurements to test these hypotheses can be collected by deploying dense monitoring networks comprised of inexpensive digital sensors (Holden et al. 2011; Holden and Jolly 2012; Isaak et al. 2010; Isaak and Horan 2011). Figure 3 shows example sensor networks deployed in 2010 across a topographically complex 6,900 km² mountain river basin in central Idaho.

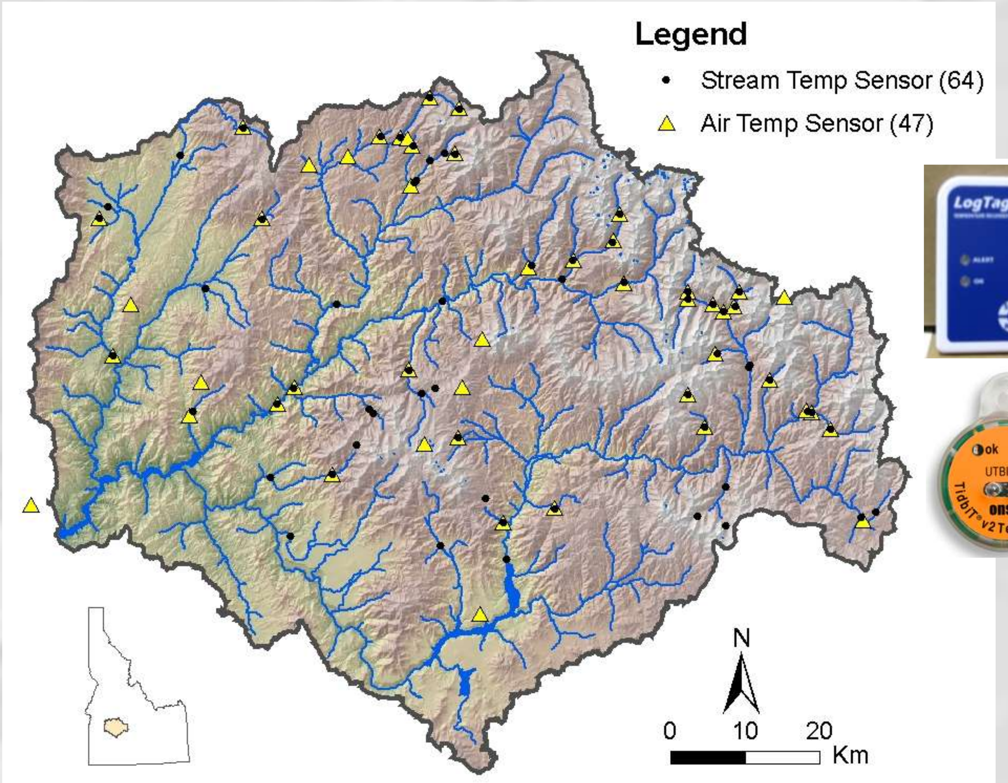


Fig 3. Locations of air (valley bottom and ridgeline) and stream temperature sensors deployed across the Boise River basin in central Idaho in 2010. Sensors have been continuously recording hourly temperatures for the last two years. Inset photos shows example temperature sensors, which cost $20 - $110 per unit.

Air Temperature Models

Air temperature data from the sensor network were used to parameterize mixed effects microclimate regression models (Holden et al. In prep; 2011) that downscaled gridded air temperatures from the 15 kilometer resolution RegCM3 climate model (Hostetler et al. 2011) and 4 kilometer gridded air temperatures (Abatzoglou 2012) to a 30 meter resolution. The microclimate models (fit at both monthly and daily timesteps) treated gridded air temperatures and topographic covariates as fixed effects and sensor site as a random effect. Additionally, the daily timestep model used humidity, atmospheric pressure, and vorticity in the downscaling process to capture interactions between terrain, cloud cover and large-scale pressure patterns.

Scatterplots in Figure 4 show similar temporal relationships between predicted and observed air temperatures from the regional climate model (RCM) and the microclimate model at a monthly timestep. These relationships, however, obscure important heterogeneity in air temperature changes across the river basin. Most notably for stream temperatures—air temperatures are predicted to change less in valley bottoms than on ridgelines (Figure 5).

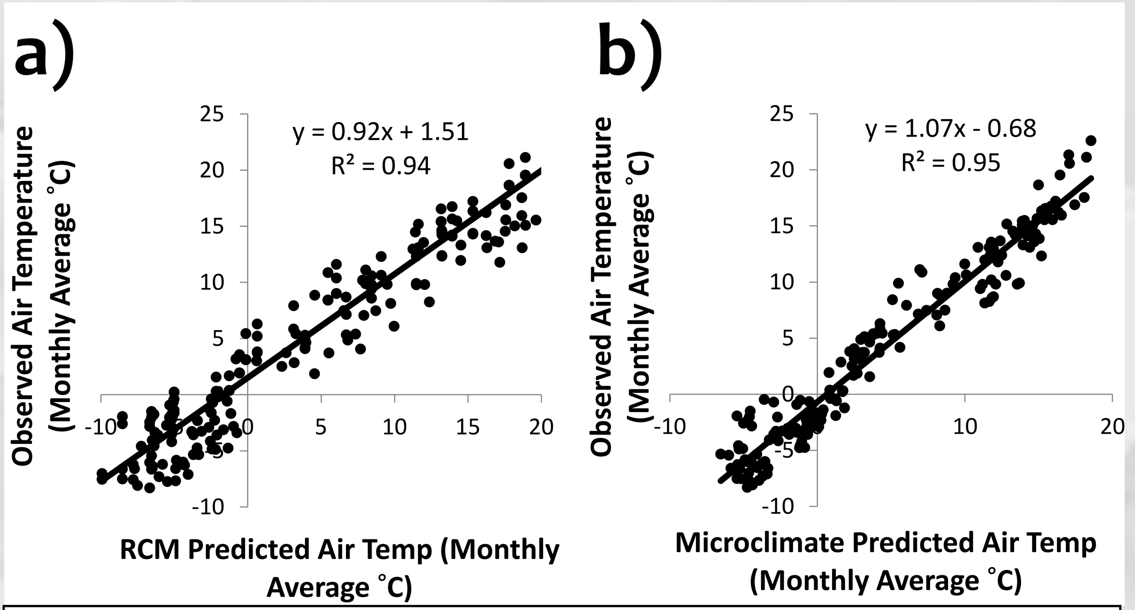


Fig 4. Comparison of monthly mean air temperatures observed at 44 sensor sites across the Boise River basin (13 month period from August 2010–August 2011) to predictions from the RCM (a) and the microclimate model (b).

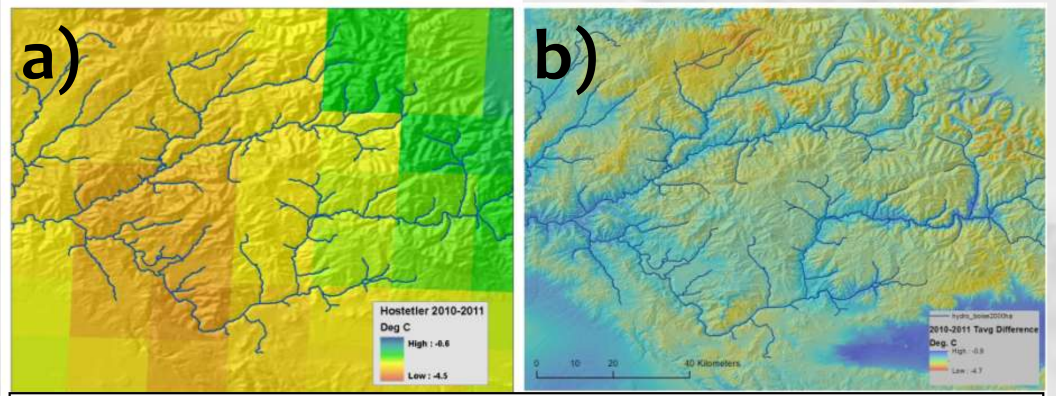


Fig 5. Maps showing inter-annual change in mean August air temperatures between 2010 and 2011 for the RCM (a) and the microclimate model in the Boise River basin (b). The microclimate model predicts that valley temperatures change less than ridgelines.

The basic prediction from the microclimate model was subsequently validated with empirical sensor measurements during the summers of 2011 and 2012. Mean June/July air temperatures across the basin in 2012 were warmer than 2011 (+2.1 ˚C) but air temperatures measured in valleys changed 20% less (+2.0 ˚C) than those at ridgelines (+2.4 ˚C; Figure 6).

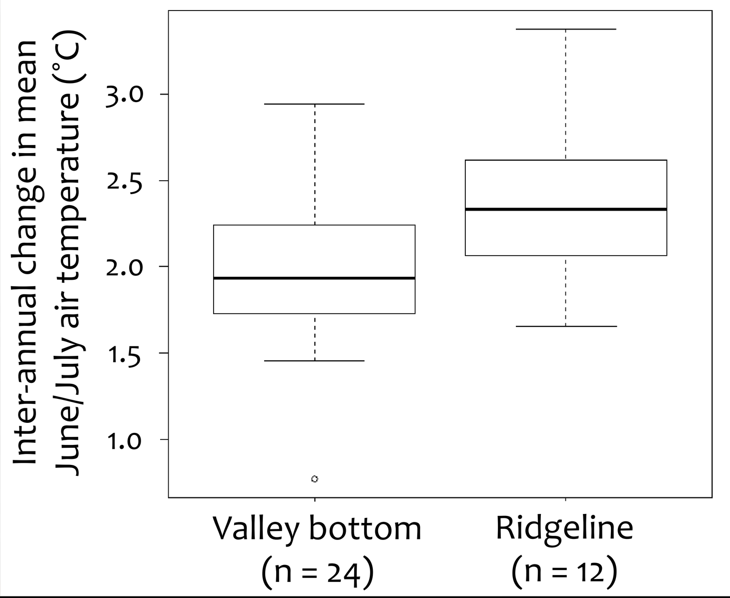


Fig 6. Differences in mean June/July air temperatures between 2011 and 2012 measured at 36 air sensor sites across the Boise River basin. Difference in mean temperatures at valley sites (left box plot) were significantly smaller than those at ridgeline sites (right box plot; p = 0.03).

Discussion

With only a few years of data from a network of inexpensive sensors, it is possible to develop and validate a microclimate model that enables high-resolution historical climate reconstructions (Figure 5) or forecasts through linkage to existing RCMs (Figure 7). Microclimate models allow us to better understand and predict climate effects on stream temperatures.

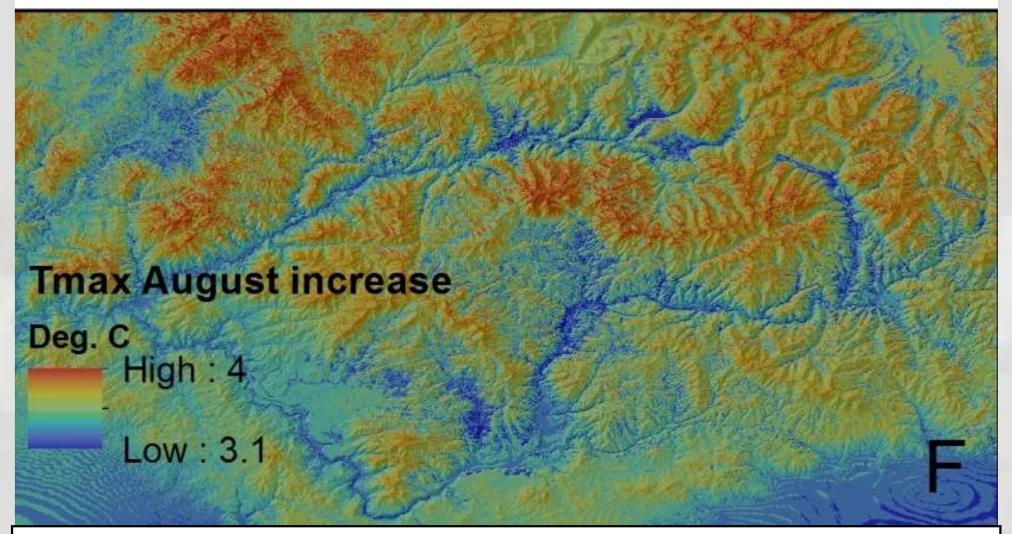


Fig 7. Map of differences in the Boise River basin for maximum August air temperature between historic (1979-2010) and future periods (2036-2046) predicted with the microclimate model forced by the RCM.

Results from the microclimate model in the Boise River basin lend support to the decoupling hypothesis (Figure 2) for explaining the discrepancy between long-term trends in air and stream temperatures (Figure 1). However, the differences observed between valley floor and ridgeline air temperatures were not so large that factors associated with the differential sensitivity hypothesis may be discounted. Empirical measurements of stream temperatures across the Boise River basin, for example, indicate that cold, high elevation streams usually warm less than lower elevation streams across years (i.e., converging regression slopes in Figure 8). This pattern could arise from the proximity of high elevation streams to more persistent snowpacks and colder, or more abundant, groundwater inputs. Geomorphic considerations related to channel slope and valley morphology or stream size and riparian conditions have also been put forth as potential factors affecting stream temperature sensitivity. More research is needed to resolve these details and fully understand the array of factors that cause stream temperature responses to climate forcing.

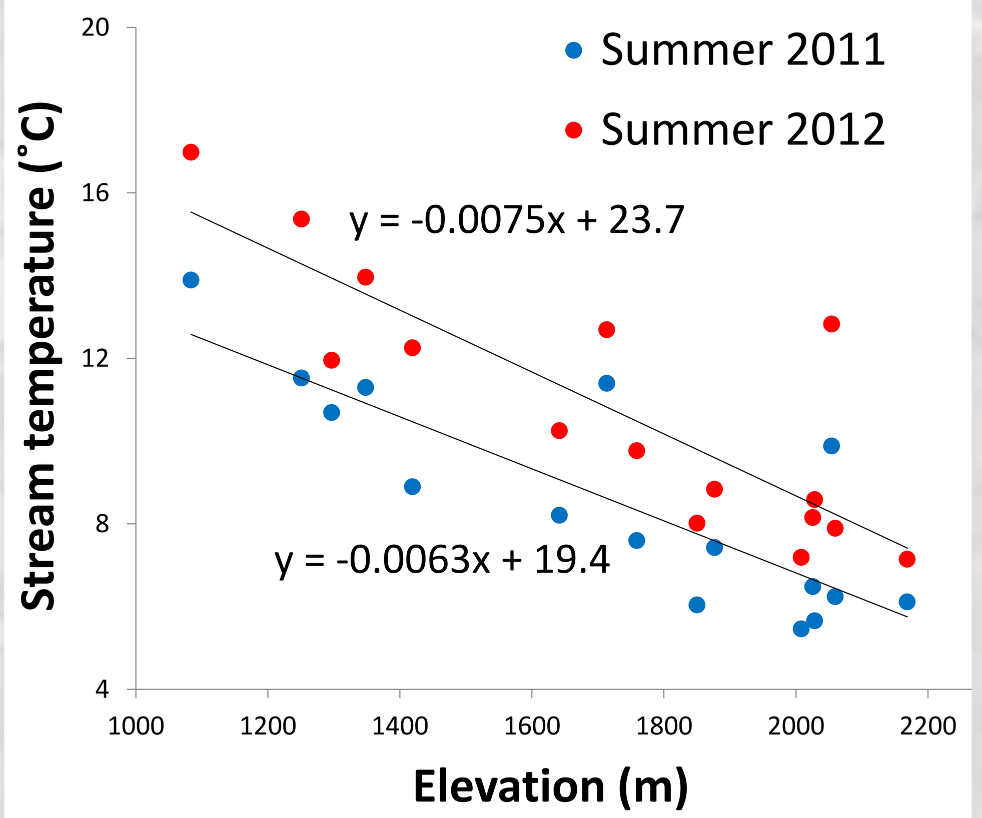


Fig 8. Stream temperature changes in the Boise River basin between the summers of 2011 and 2012. Warmer streams at low elevations usually change more than cold streams at high elevations. Slope parameters of regression equations describe the stream temperature lapse rate in ˚C/m.

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Websites for more…

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