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SCALING RELATIONSHIPS ACROSS MODELING RESOLUTIONS IN MOUNTAIN HEADWATERS: UNDERSTANDING CLIMATE CHANGE IMPACTS ON ROCKY MOUNTAIN HYDROLOGY IN A NUMERICAL MODELING CONTEXT

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EXECUTIVE SUMMARY

One in 10 Americans sources water from the Colorado River [1], and 85% of that streamflow is generated in Rocky Mountain headwater catchments [2] that have been shown to be especially sensitive to a changing climate. Global climate models and regional hydrologic models are known to perform poorly in these regions [4–6], casting doubt on water supply forecasts for the next century. In this work, we developed relationships across scales to better model climate change impacts on headwater hydrology. First, we described a new method to parameterize high- and hyper-resolution models where traditional calibrations are infeasible. Second, we demonstrated that high-resolution simulations show more sensitivity to climate changes, indicating that the coarse-resolution models used now may overpredict future water supply. Finally, we compared extensive remote-sensing, point, and field observations to modeling predictions of snowpack, allowing for cross-validation across spatial and temporal scales.

RESEARCH CHALLENGE

Mountain regions are complex, causing nonlinear interactions between water and energy fluxes that are difficult or impossible to model with simple algorithms. Understanding how these interactions scale across modeling resolutions is critical to improving predictions of water supplies under climate change. This problem is important to municipalities, farmers, and water managers across the Southwest United States who depend on water supplies generated in Rocky Mountain headwaters. Local and federal governments need to develop new policies to cope with snowpack reductions in the Rockies. Finally, as hydrologists push toward a new grand challenge of hyper-resolution modeling, new parameterization techniques across scales will be needed.

METHODS & CODES

We modeled a representative headwater catchment in the physically based code Parflow–CLM [7,8] at 1-km and 100-m resolution. These models were used to do extensive sensitivity experiments across parameter sets and future climate projections to understand how results and predicated behavior changed across different scales.

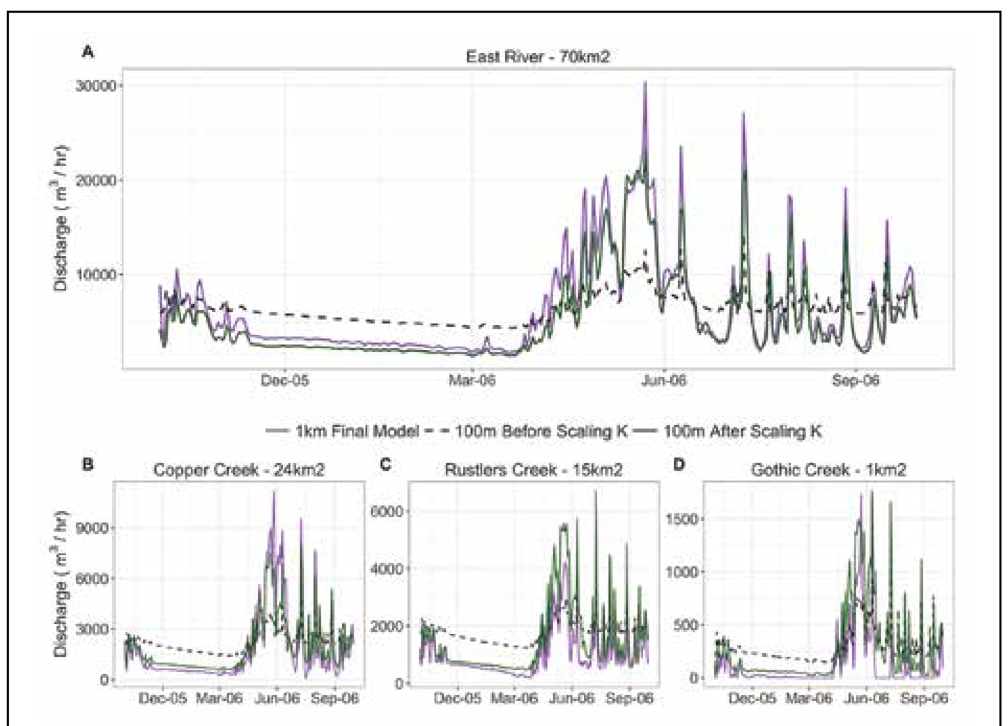

Figure 1: Streamflow plotted in the East River and three sub-basins for the initial 100-m (high-resolution) parameterization and the 100-m parameterization after applying the new scaling technique indicate a dramatic improvement in scaling model inputs to match winter baseflow, spring peak flow, and summer monsoon flow.

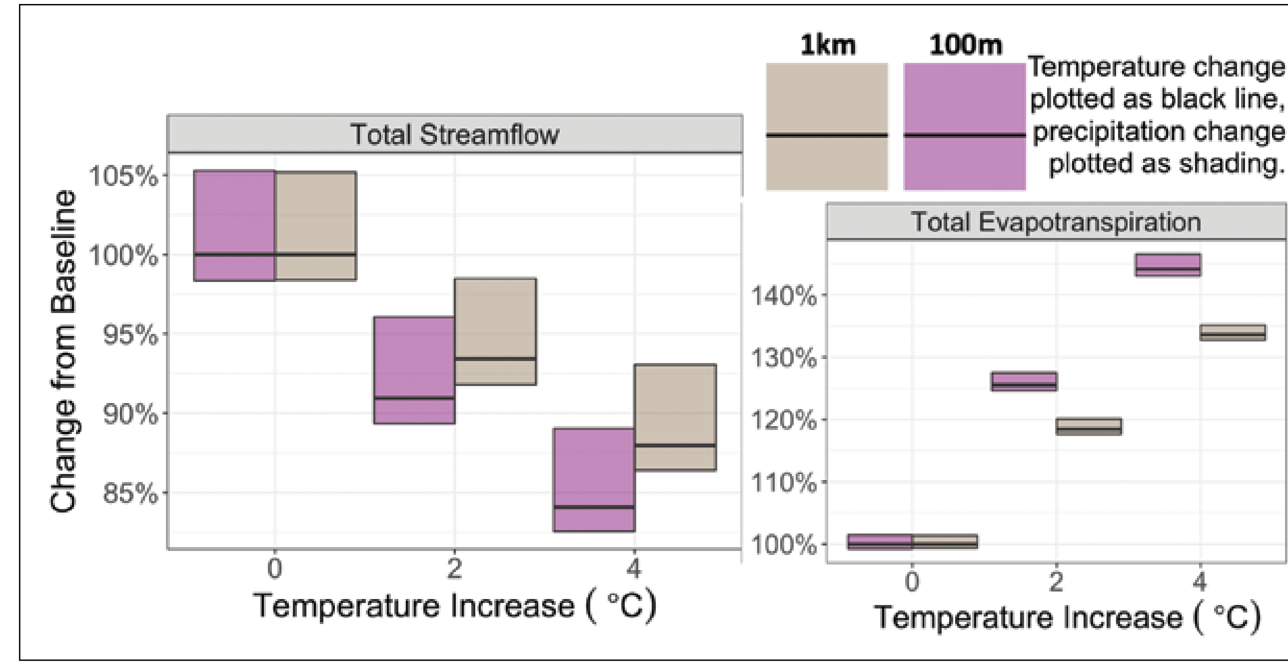

Figure 2: At higher resolution, larger reductions to streamflow are predicted in response to increasing temperatures. This pattern likely is driven by increases in evapotranspiration at 100 m as temperatures increase. Additionally, temperature increases (black lines) are shown to have a larger effect than precipitation changes (shaded bars), especially for evapotranspiration.

RESULTS & IMPACT

Results from the first study (Foster, et al., *Hydrologic Processes*, in review, 2018) have produced a new method that is consistent with the underlying physically based mathematics to scale a critical hydrologic parameter—hydrologic conductivity—across modeling resolutions. These results allow calibration of a coarse-resolution model that can then be applied at scales where calibration is impossible. Given that hyper-resolution models are considered a current "grand challenge" in the field of hydrology [9], these results are critical to both hydrology and physical modeling fields.

The second study (Foster, et al., *Geophysical Research Letters*, in preparation, 2018) demonstrated that climate uncertainty is on a similar scale to modeling uncertainty, highlighting that existing predictive models may overestimate water supplies for the coming century and that modeling uncertainty needs to be included to better predict future water availability.

WHY BLUE WATERS

The Blue Waters project provided the graduate support to make this work possible. Further, it provides one of the best high-performance computing systems for applications, such as this one, that require parallelization. In addition, the consistent advice and guidance of my Blue Waters point of contact expanded my knowledge of high-performance computing systems and applications.

PUBLICATIONS & DATA SETS

Foster, L.M. and R.M. Maxwell, Using sensitivity analysis and model resolution to scale effective hydraulic conductivity and Manning's n parameters in a mountain headwater catchment. *Hydrologic Processes*, in review (2018).

Foster, L.M., K.H. Williams, and R.M. Maxwell, When Does Uncertainty Matter While Modeling Climate Change in Mountain Headwaters? Contrasting model resolution and complexity under a changing climate in an alpine catchment. *Geophysical Research Letters*, in preparation (2018).

Lauren Foster is a PhD candidate in the Hydrologic Sciences and Engineering Department of the Colorado School of Mines, working under the supervision of Reed Maxwell. She expected to graduate in August 2018.