Evaluating Stream Discharge Simulations with the Fully Coupled WRF WRF-Hydro Model Framework in a Mountainous Snow-Dominated Watershed

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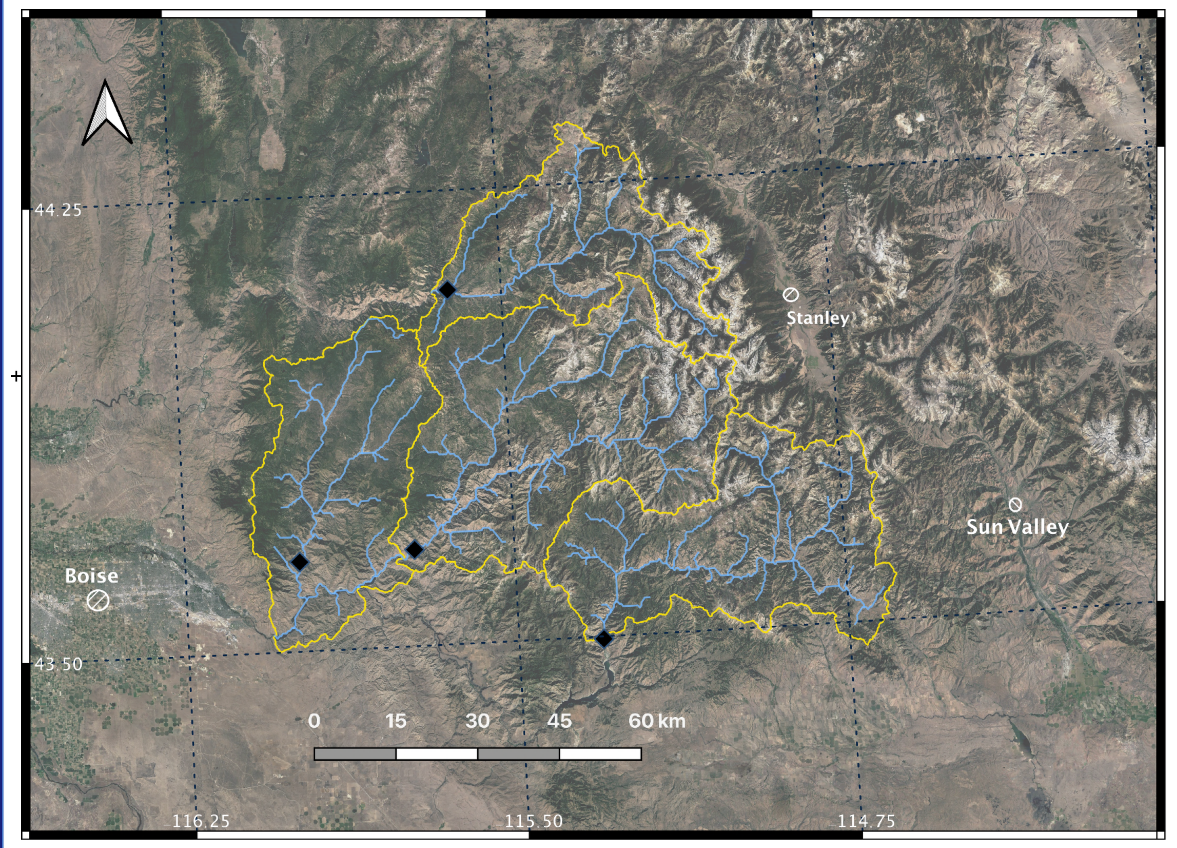
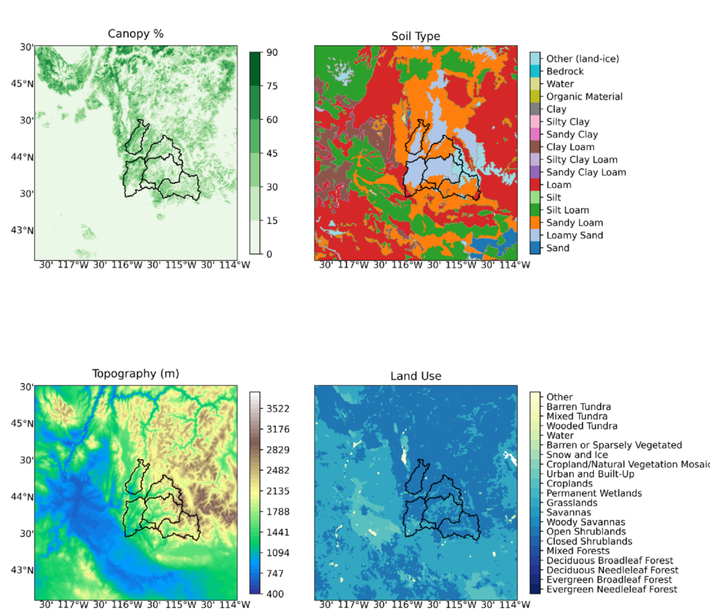
Introduction

- Modeling river discharge, especially in mountain regions, is often limited by the quality of the precipitation input
- Precipitation in mountain areas is highly spatially variable and can be under sampled by gagues, especially for snowfall
- Convection-permitting numerical weather models offer a promising pathway for recreating precipitation states in mountain watersheds
- This study uses the output of a 20-year, convection permitting configuration of the Weather Research and Forecasting (WRF) model to run the WRF-Hydro (Gochis et al, 2018) hydrologic model for four headwater basins in the Boise River Basin, Idaho, USA.
- We also test the impact of coupling WRF-Hydro with WRF. Resolved overland and subsurface flow redistribute soil moisture which can influence atmospheric boundary layer development

Study Area: Upper Boise River Basin





- Moores Creek, South Fork Boise, Middle Fork Boise, South Fork Payette
- All are headwaters, snow-dominated basins underlain by cretaceous granitodiorite and sandy-loam soils
- Highest peaks are >3000 m tall
- LULC primarily evergreen forest and lowland shrubs

WRF-Hydro Model Calibration

- WRF-Hydro model parameters are calibrated using an automated Dimensioned Dynamic Search (DDS; Tolson 2007) algorithm applied 200 iterations to each basin, independently
- Calibration is performed for a two-year period

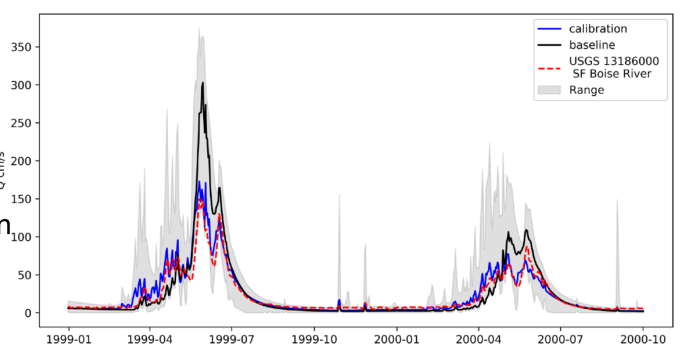
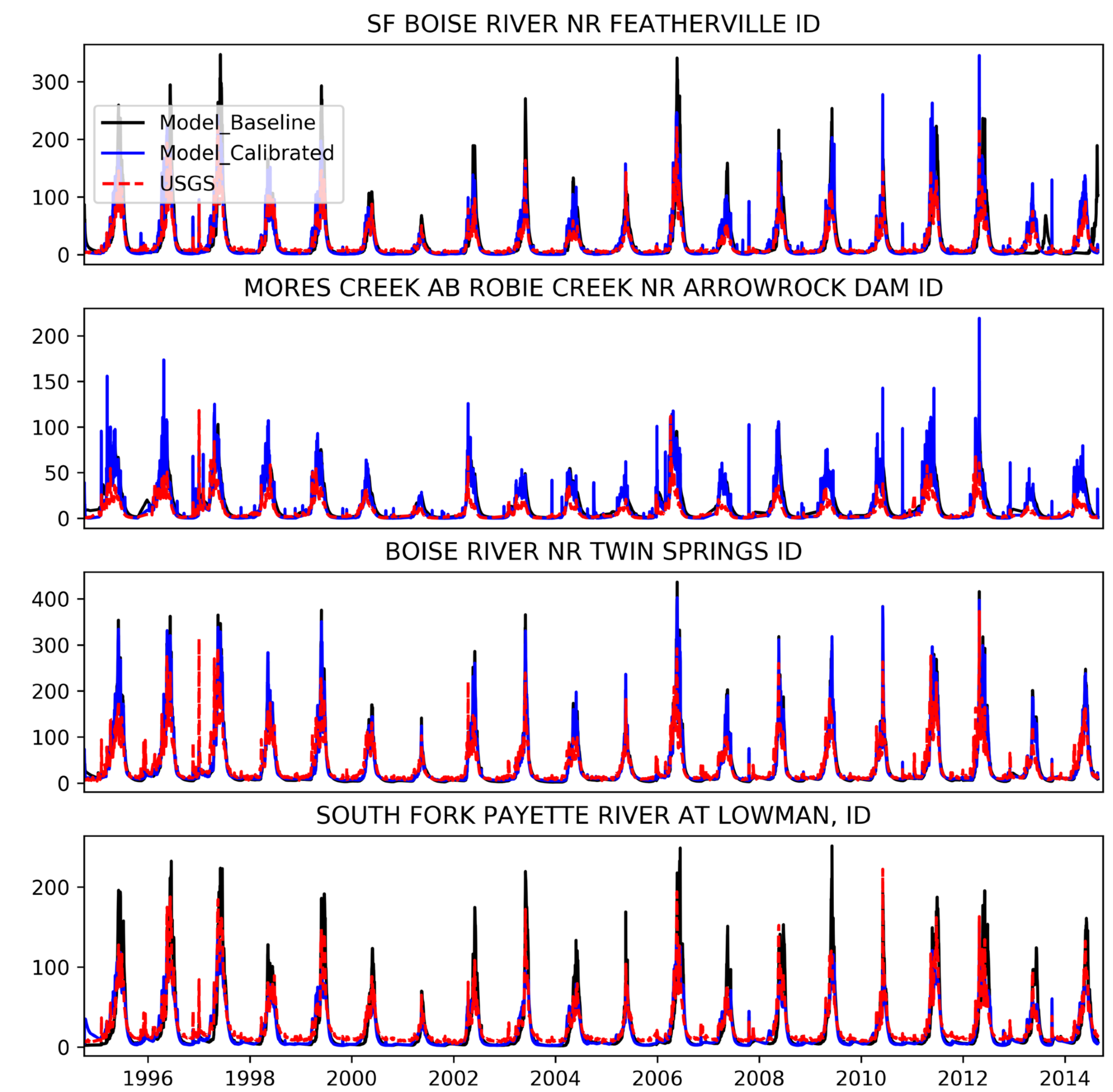


Figure 1: Example output from the calibration run for the SF Boise River

Results—Uncoupled WRF-Hydro



Basin	Run	*KGE*	*NSE*
Moores Creek (MC)	calibrated	-0.154	0.717
	baseline	-0.33	0.645
SF Payette (SFP)	calibrated	0.801	0.851
	baseline	0.568	0.858
SF Boise (SFB)	calibrated	0.693	0.899
	baseline	0.304	0.821
MF Boise (MFB)	calibrated	0.637	0.846
	baseline	0.583	0.835

Figure 2: Modeled and Observed discharge hydrographs for Moore's Creek, the South Fork Boise, Middle Fork Boise, and South Fork Payette for 1994—2014. **Table 1:** shows the "Nash-Suffcliffe" efficiency (NSE) and the Kling-Gupta Efficiency (KGE) for the modeled discharge compared with the observed stream hydrographs.

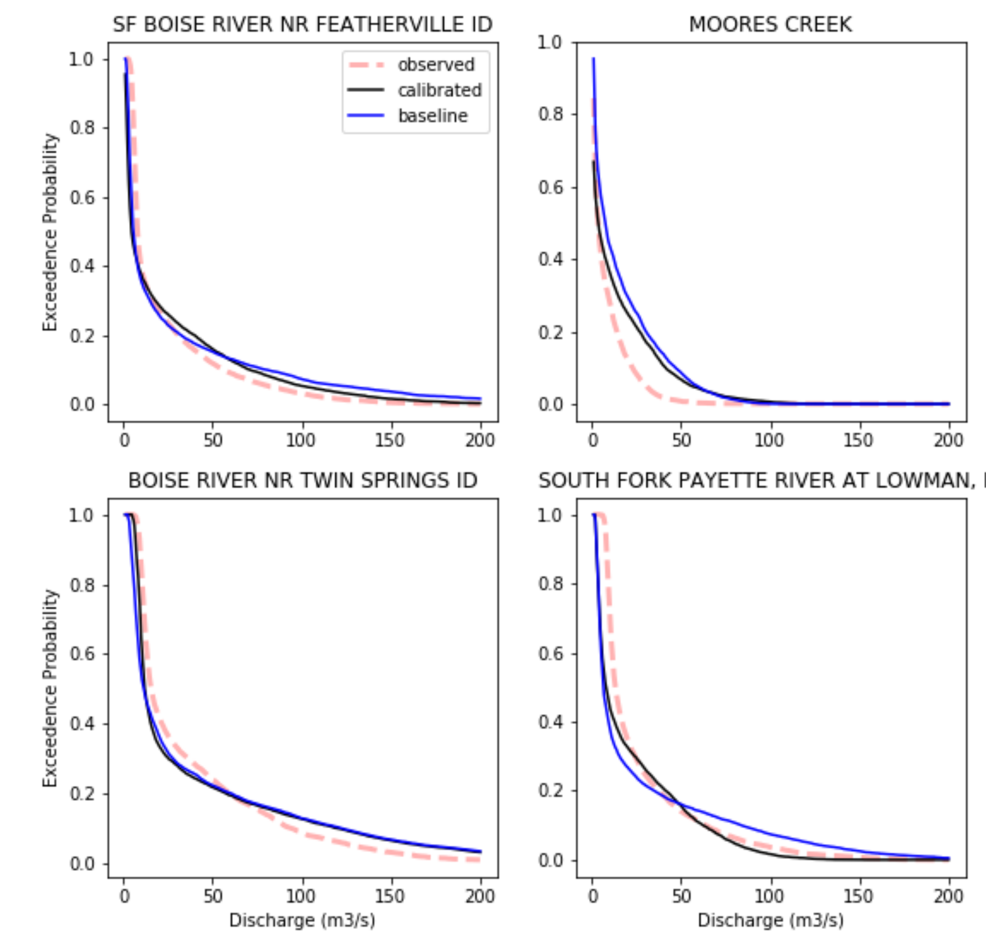


Figure 3: Excellence Probability (EP) curves for each river basin. EP is the probability that discharge exceeds a given threshold flow (x-axis)

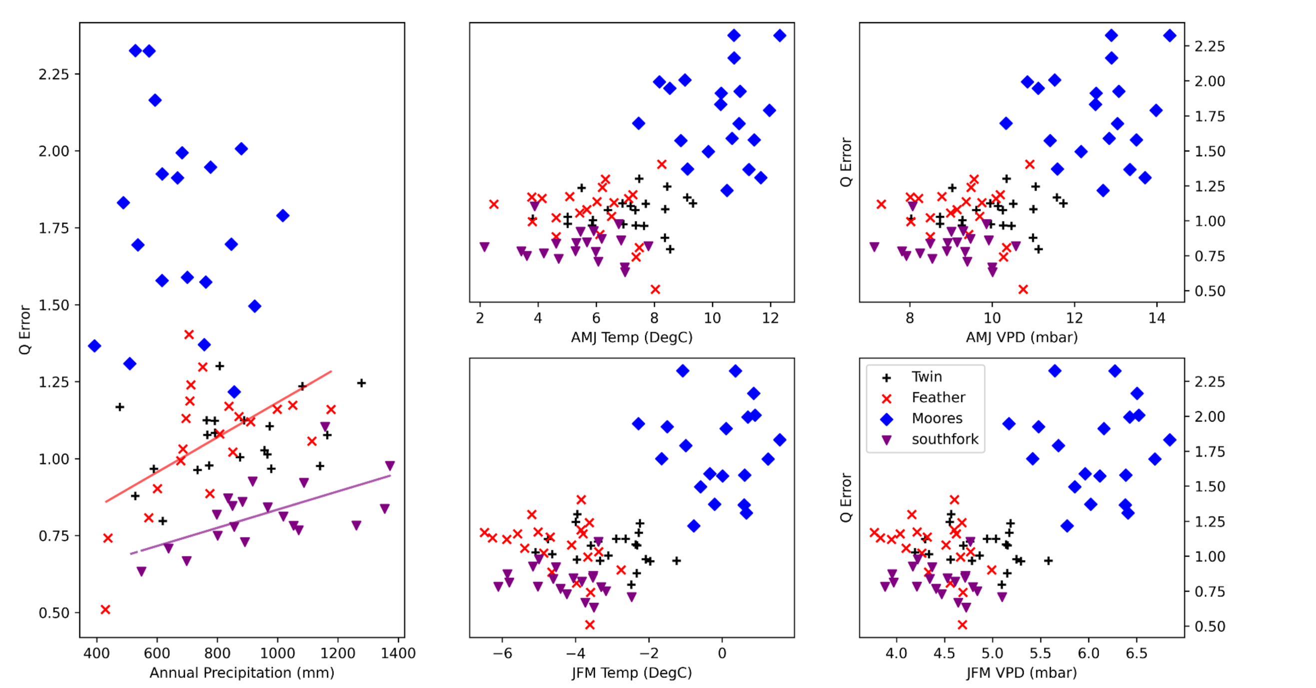
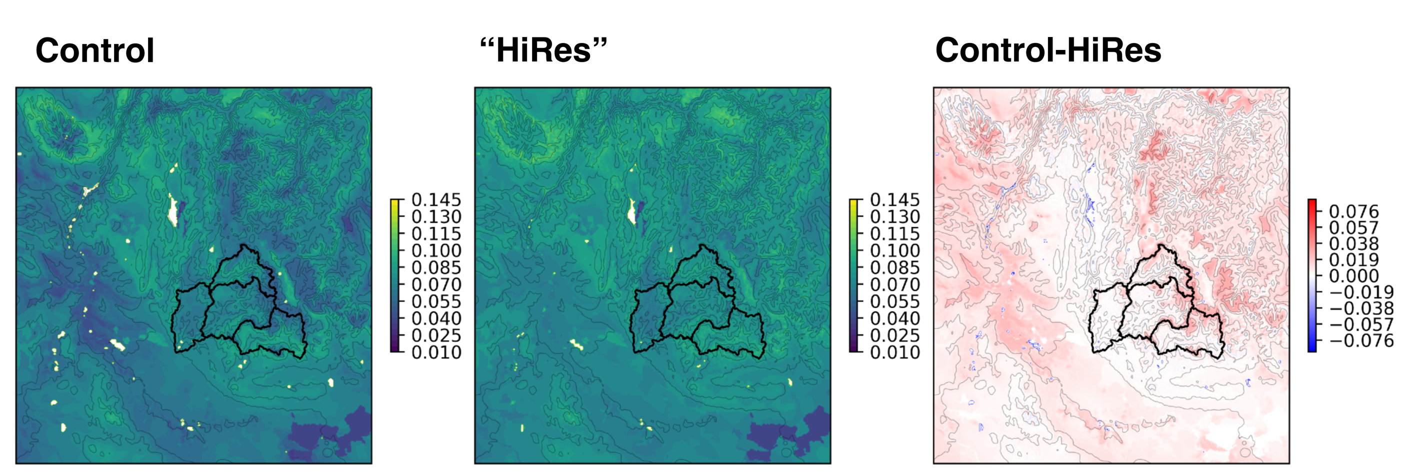


Figure 4: Correlations between annual stream discharge error (the ratio of the modeled discharge to the observed) and watershed total annual precipitation (left; mm) and April-May-June (AMJ) and January-February-March (JFM) average temperature and Vapor Pressure Deficit (VPD; mbar). Lines denote a significant linear relationship with p > .01

Initial Soil Moisture Conditions — Coupled Experiments

Figure 6 (below): The initial soil moisture conditions for the WRF Coupled Experiments. See text for description



Fully Coupled WRF/WRF-Hydro

We run WRF "fully coupled" with WRF-Hydro for 2 months (May - July) and compare turning on/off flow routing (the "control" and "routing") scenarios. We also test the impact of initial soil moisture conditions. The "HiRes" scenario uses initial soil moisture conditions created from an offline WRF-Hydro spinup with overland + subsurface flow turned on.

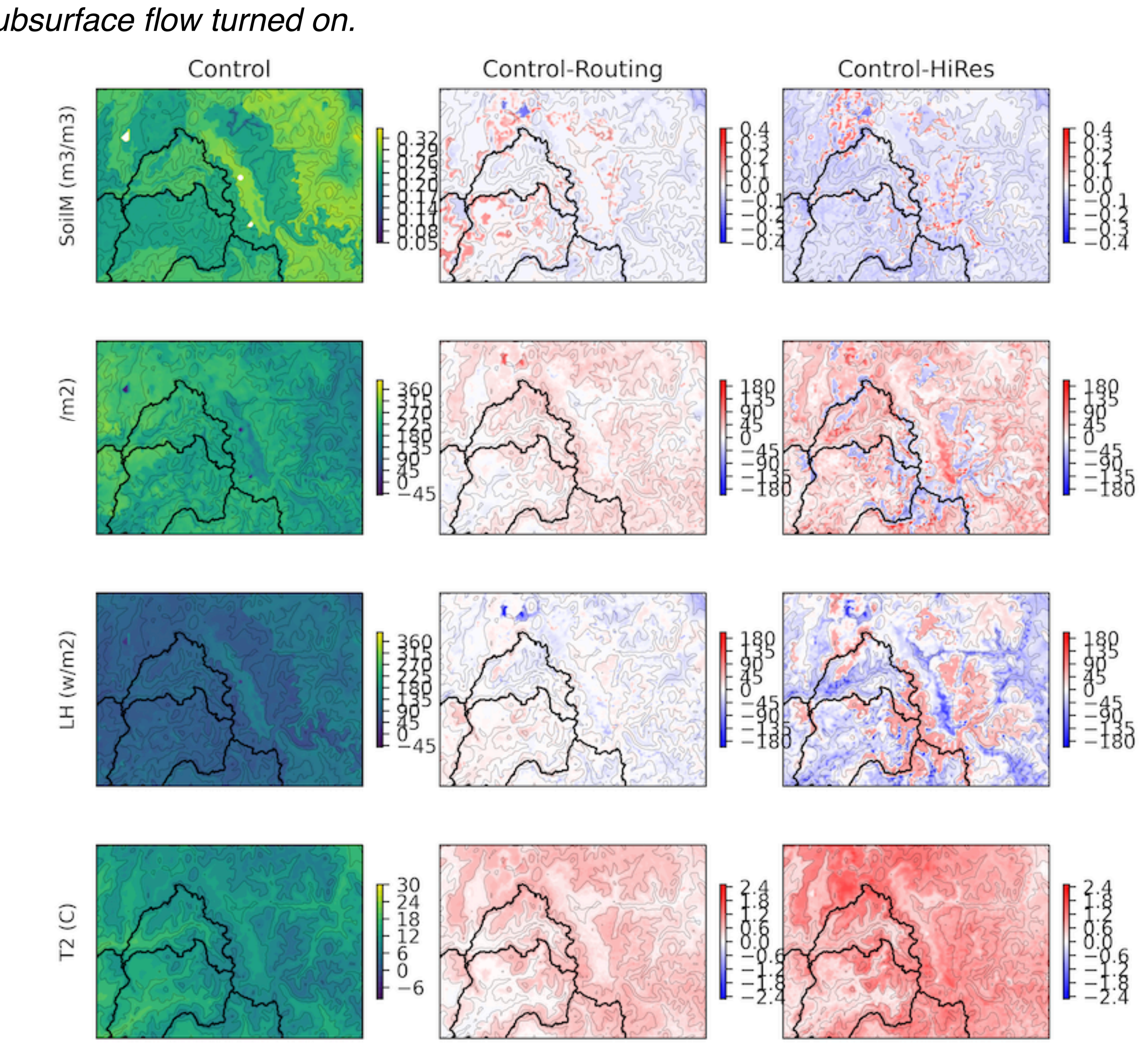
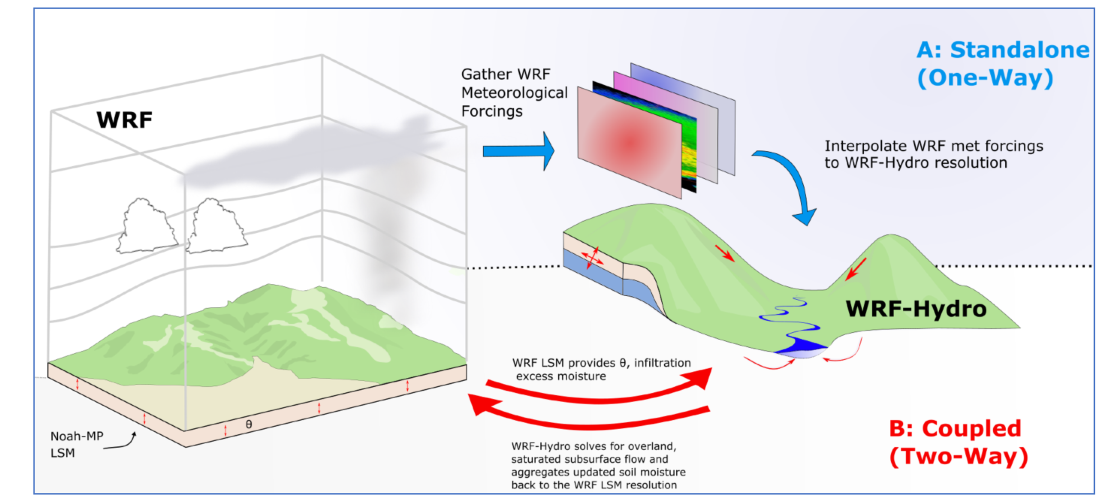


Figure 5: Average energy budget components for the uncoupled model scenarios (May-July). Left is control, middle is the control minus the "routing scenario" and with is the control minus the "HiRes" scenario.

Methods



- The Weather Research and Forecasting (WRF; Skamrock 2008) model was run for 20-years using the options described in Table 1, both uncoupled and "coupled" with WRF-Hydro.
- Meteorological conditions (wind, precipitation, shortwave, long wave, pressure, and humidity) are downscaled to the WRF-Hydro Model Resolution (250m)
- Each basin is run and calibrated individually (four total; see WRF-Hydro Calibration section)
- Discharge is compared with USGS stream gauges
- WRF-Hydro (Gochis, 2018) effectively adds infiltration and saturation excess overland and saturated subsurface flow equations on top of the Noah-MP (Nui, 2011) land surface model.
- WRF-Hydro uses a kinematic wave approximation for overland flow, a saturated subsurface flow formulation following Wigmosta and Lettenmeir (1994) and a Muskingum-Cunge channel routing formulation in addition to a conceptual groundwater model.

	WRF (v3.8.1)
Model Options	
Grid resolution (km)	3,1
W-E Dimension (cells)	340, 349
N-S Dimension (cells)	290, 328
Vertical Levels	50,50
Timestep	15s
Microphysics	Thompson
Land Surface Model	Noah-MP (Option X); Noah-MP + WRF Hydro
Surface Layer	Monin-Obukhov
Planetary Boundary Layer (PBL)	Mellor-Yamada-Janjic

Table 2: WRF Physics description. The same inner-domain is used for the coupled model experiments and is run with lateral boundary conditions created during the uncoupled run, using the standard "ndown.exe" program distributed with WRF.

Discussion and Conclusions

- Both before and after calibration, the uncoupled model performs reasonably well at capturing the seasonal cycle of discharge for the 20 year period.
- Moores creek watershed performs worse than the other watersheds with significantly (2x in some years; see Figure 3) higher modeled discharge. It is lower elevation and generally warmer than the other watersheds. Ongoing work is assessing potential sources of error.
- For most watersheds, the low-flow conditions are significantly underestimated than what is observed (Figure 3). We speculate that model physics is likely the primary source of this bias.
- The model discharge error is generally uncorrelated with the JFM or AMJ temperature or VPD. The error in stream discharge does tend to correlate positively with higher precipitation (p>.01) for the Southfork Payette and Southfork of the Boise (Figure 4).
- The soil moisture state influences the surface energy budget and two meter air temperature. Analyzing the impact of coupling on precipitation is ongoing

References

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Acknowledgements:

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