Improving rainfall-runoff model reliability under non-stationarity of model parameters – a hypothesis testing based framework

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Hydrologic models are essential tools to predict climate change impacts on water availability. Most associated applications involve forcing calibrated models with downscaled general circulation model simulations for specific emission scenarios. Doing so implicitly assumes future applicability of models calibrated over historical observations. However, sustained climatic shifts exceeding observed ranges of variability can interact with vegetation, soil moisture and snow processes to produce a modified rainfall-runoff relationship, introducing significant uncertainties in simulated impacts. One way to consider climate change impacts on model parameterization is to regionalize model parameters in space, and then apply developed relationships to project their changes in time – trading space-for-time (TSFT). We explore 35 hypotheses on probable model parameter changes with climate by designing experiments that consider climatic, physical, and combined climatic-physical similarities to trade space-for-time. Our experiments are based on a recently developed Whittaker-biome based TSFT framework that has shown promising results when simulating mean annual runoff. They are conducted for four watersheds in the conterminous United States that undergo a biome transition from boreal forests to temperate seasonal forests due to significant climate change between 1980-1990 and 1999-2009. We note that performance deterioration depends upon the extent of climatic deviation from historical observations. For the two most severely affected watersheds, the prediction bounds obtained from behavioural parameter sets calibrated using pre-change observations only enveloped observed runoff 50.7% and 47.9% of the time. This was associated with errors in simulated peak flow timing; observations for these watersheds differed from simulations by 16 and 24 days in the post-change period. Our experiments showed that hypotheses which used combined climatic-physical similarities to trade space-for-time consistently improved simulation performance for all four watersheds. These improvements were attributed to updated snow and vegetation parameters. Our most successful experiment enveloped observed runoff 85.3% of the time (median across all watersheds), and constrained runoff timing errors to 2 days.