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Probabilistically Constrained Climate Projections of the Surface Water Balance over Land

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Climate model simulations from the fifth phase of the Coupled Model Inter-comparison Project (CMIP5) are the main tools for projecting changes in the climate system. However, differences between models with respect to their process parameterizations, and their land surface and hydrological modeling schemes can be considerable. Consequently, future changes in the terrestrial surface water balance, represented as the difference between long-term mean precipitation (P) and evapotranspiration (ET), remain highly uncertain. To reduce this uncertainty in the full climate model ensemble we use an extension of the “emergent constraints” framework, in which each model has a probability of being included in the constrained ensemble. First, an observable present-day metric that is related to the projected hydrological changes needs to be identified. Here we test several previously proposed controls of the surface water balance, e.g. the phasing between P and potential ET, the variance of annual P – ET, land cover, climate modes of variability, etc. Subsequently, model estimates of the chosen metric are evaluated against observations. This provides the basis for a constrained model ensemble with reduced uncertainty. For the evaluation we adapt techniques that were initially developed for weather forecast ensembles to the climate change setting; information at each land grid cell is considered as an individual forecast. Through a Markov Chain Monte Carlo (MCMC) algorithm we determine the probability of each model to be included in the ensemble that optimizes the agreement with observations. Sampling with these optimized probabilities leads to constrained model ensembles from which the distribution of projected changes in the surface water balance at the grid cell level are obtained. Overall, this study provides improved insights on the impacts of climate change on future hydrological conditions, as well as a new methodological framework for constraining other variables of interest in a probabilistic fashion. Moreover, the developed framework can be adapted to include multiple constraining metrics and observational estimates, as well as different criteria for estimating the agreement between models and observations.