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Prediction of annual runoff by using a Bayesian geostatistical model for combining precipitation gauge observations and runoff observations

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The aim of this work is to perform predictions of annual runoff in ungauged basins in the Voss area in Norway. Voss is located in a mountainous area where the mean annual precipitation is around 2000 mm and the spatial variability is large. Inside a study area of 80km x 80km the annual precipitation can range from 770 mm to 3200 mm within a year. The hydrological data available is limited relative to the large spatial variability: We have measurements of annual runoff from 1987-2013 from 5 catchments, where 3 of the catchments are nested. In addition, observations of annual precipitation and evaporation from 15 precipitation gauges are available.

While the observations of precipitation and evaporation are defined for point locations in the landscape, runoff observations are linked to catchment areas. To gain as much knowledge as possible from the limited data, we should exploit information from both observation types: Point and areal observations. In this study, we present a Bayesian geostatistical model for annual runoff where point and areal observations can be combined in a mathematically consistent way. In particular we are interested in exploring how the different data sources affect runoff predictions in terms of prediction mean and prediction variance, and we compare the following three observation designs:
1) An observation design where only point referenced observations are utilised, i.e observations of precipitation and evaporation.
2) An observation design where only areal referenced observations are utilised, i.e runoff observations from nearby catchments.
3) An observation design where all available observations are utilised: Both point and areal referenced observations.
Each observation design is evaluated based on its ability to perform spatial predictions of annual runoff in ungauged basins around Voss, and its ability to estimate future annual runoff in gauged or ungauged basins. The latter is possible because the model includes a Gaussian spatial component that represents the average spatial variability of the runoff generating process. This component is estimated based on several years of observations, and can be interpreted as the spatial variability caused by the climate in the study area. Thus, it also provides valuable information about the annual runoff we can expect in the future with uncertainty estimates.

The analysis is performed through leave-one-out cross-validation on the Voss dataset. To reduce the computational complexity, the Gaussian field is formulated as the solution to a stochastic partial differential equation (SPDE). This makes it possible to use integrated nested Laplace approximations (INLA) to generate faster predictions.

The results show that on average we obtain the most accurate runoff predictions when all available observations are utilised in the analysis. However, including observations of precipitation sometimes leads to systematic biases in the predictions and an underestimation of the prediction uncertainty. This can be explained by the strong climate in the study area: As long as the climate is constant and the observation design is static, we typically do the same error from one year to another. We can get similar patterns also for simulated datasets.