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Progress on improving streamflow forecasting has been made in several key areas. These include data assimilation methods, assessment of model uncertainty and contributions to the NWS DMIP-2 such as an investigation of the utility of the NOAA-NOHRSC SNODAS data in the region.

Data Assimilation

A study was undertaken in which we the ensemble Kalman filter (EnKF) was used to update states in a distributed hydrological model by assimilating observations of streamflow. It is hoped that the next generation of streamflow prediction systems will beb based on distributed models, but many obstacles remain to be surmounted, such as calibration and assimilation. In terms of assimilation of a streamflow, it was demonstrated that the standard implementation of the EnKF is not very effective because of the largely non-linear relationships between model states and observations. Transforming streamflow into log space before computing error covariances improved filter performance. We also demonstrated that model simulations improve when we use a variant of the EnKF that does not require perturbed observations. Our attempt to propagate information to neighbouring basins was unsuccessful, generally due to inadequacies in modeling the spatial variability of hydrological processes (see Figure 1 below). This brings us back to the point that calibration of distributed conceptual and "physically based" models remains a limiting factor in their ability to realize the significant performance improvements over lumped models. New methods are needed to produce ensemble simulations that both reflect total model error and adequately simulate the spatial variability of hydrological states and fluxes.

Model System Uncertainty; Interplay of model Structure and Parameters

Our ongoing theme of assessing total modeling system uncertainty had also received attention. In a new framework developed to understand the interactions of model structure and parameter dependencies, seventy-nine unique model structures were created by combining components of four existing hydrological models. These new models were used to simulate streamflow in two of the basins used in the MOdel Parameter Estimation eXperiment (MOPEX)—the Guadalupe River (Texas) and the French Broad River (North Carolina). Results show that the new models produced simulations of streamflow that were at least as good as the simulations produced by the models that participated in the MOPEX experiment. The range of model performance was however much larger in the Guadalupe River (the driest basin) than in the French Broad River (the wettest basin): differences in model performance in the Guadalupe River can be attributed in part to the parameterization used to simulate saturated areas. Further work is needed to evaluate model simulations using multiple criteria in well-instrumented catchments, and to assess the amount of independent information in each of the models. This work aids both identifying the most appropriate model structure for a given problem and to quantify the uncertainty in model structure, which is a necessary part of any data assimilation strategy.

Similarly, we performed experiment to test the sensitivity of a temperature index snow model of hierarchical complexity (i.e. additional process representation is easily added to the pre-existing model without changing structure) to increasing errors in forcing data. The models were calibrated using observed forcing and validation data and later run with increasingly degraded forcing data. It was found that for most locations additional complexity usually produced a superior simulation than the simpler models even when the input data was very noisy (but unbiased). Some locations displayed larger sensitivity and for a given error in the forcing a simpler model performed equally well or better than a more complex model. The question still remains as to whether the performance of a full surface energy balance model will be superior to a temperature index model; this is largely due to uncertainties of and sensitivities to the forcing data needed for these more complex models. It seems that the NWS has not committed to a more complex model precisely for these reasons. We have implemented a surface energy balance model into TopNet and will explore this matter in related work funded by NOAA-OAR.

Efforts snow modeling and the DMIP-2 Experiments

The NWS Distributed Model Intercomparison Project (DMIP-2) is centered on two basins in the Californian Sierra: the North Fork of the American and the East Fork of the Carson. We have performed experiments using the TopNet distributed model. The initial aim is to make an assessment of the SNODAS fluxes and stores via the only independent information available; that of streamflow.

Using the Carson basin initially, we undertook a step-wise calibration of TopNet (whose snow model is similar to NWS SNOW-17 model). Snow parameters were tuned first, using an objective function of root mean squared error (RMSE) from SNODAS snow water equivalent. Uniform parameter multipliers applied to all 29 sub-basins provided an “equifinal” result in which errors in one location would be compensated for by errors in another. The use of parameter multipliers is currently the standard approach to calibrating distributed models and this result underscores the difficulties of the process; largely because observations are usually not available on a distributed basis. Sub-basin calibration proved much more fruitful and the “gauge undercatch” or precipitation multiplier parameter clearly showed spatial heterogeneity when assessed against SNODAS. This result indicates errors in observed forcing data interpolation and possibly some inadequacies in snow modelling capabilities and heavily highlights the need for distributed model calibration if the benefits of such models are to be realized. Using the SNODAS snow water equivalent at a sub-basin level, we were able to achieve good results from the TopNet model. This work is ongoing in collaboration with other funded projects.

Publications in the last year:

Clark MP, Slater AG, Rupp DE, Woods DE, Vrugt JA, Gupta HV, Wagener T, Hay L (2008) A New Framework for Diagnosing Differences Between Hydrological Models, *Water Resources Research*, in press

Clark MP, RA Woods, X Zheng, R Ibbitt, AG Slater, DE Rupp, J. Schmidt, M. Uddstrom, (2008) Hydrological Data Assimilation with the Ensemble Kalman Filter: Use of Streamflow Observations to Update States in a Distributed Hydrologic Model. *Advances in Water Resources*, in press

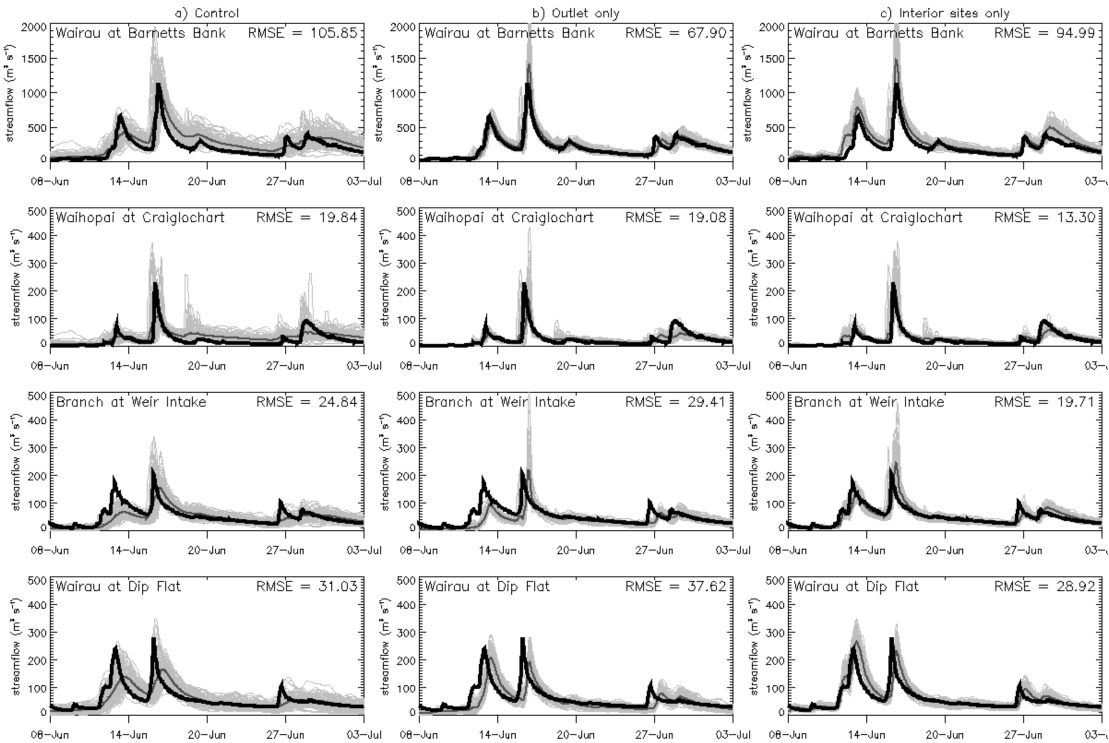


Figure 1. Taken from Clark et al., (2008) showing the Ensemble simulations for all four sites in the Wairau Basin, showing (a) the control run (no data assimilation); (b) data only assimilated at the outlet (Barnetts Bank); and (c) data only assimilated at the interior locations (Waihopai at Craiglochart, Branch at Weir Intake, and Wairau at Dip Flat). The ensemble square root Kalman filter (EnSRF) is used for data assimilation. The light grey lines are individual ensemble members, the grey line is the ensemble mean, and the thick black line is observations. Barnetts Bank, Waihopai and Dip Flat are effectively independent locations within the stream network as neither of these locations directly influences the others flow. This represents the case of neighboring and ungauged basins.

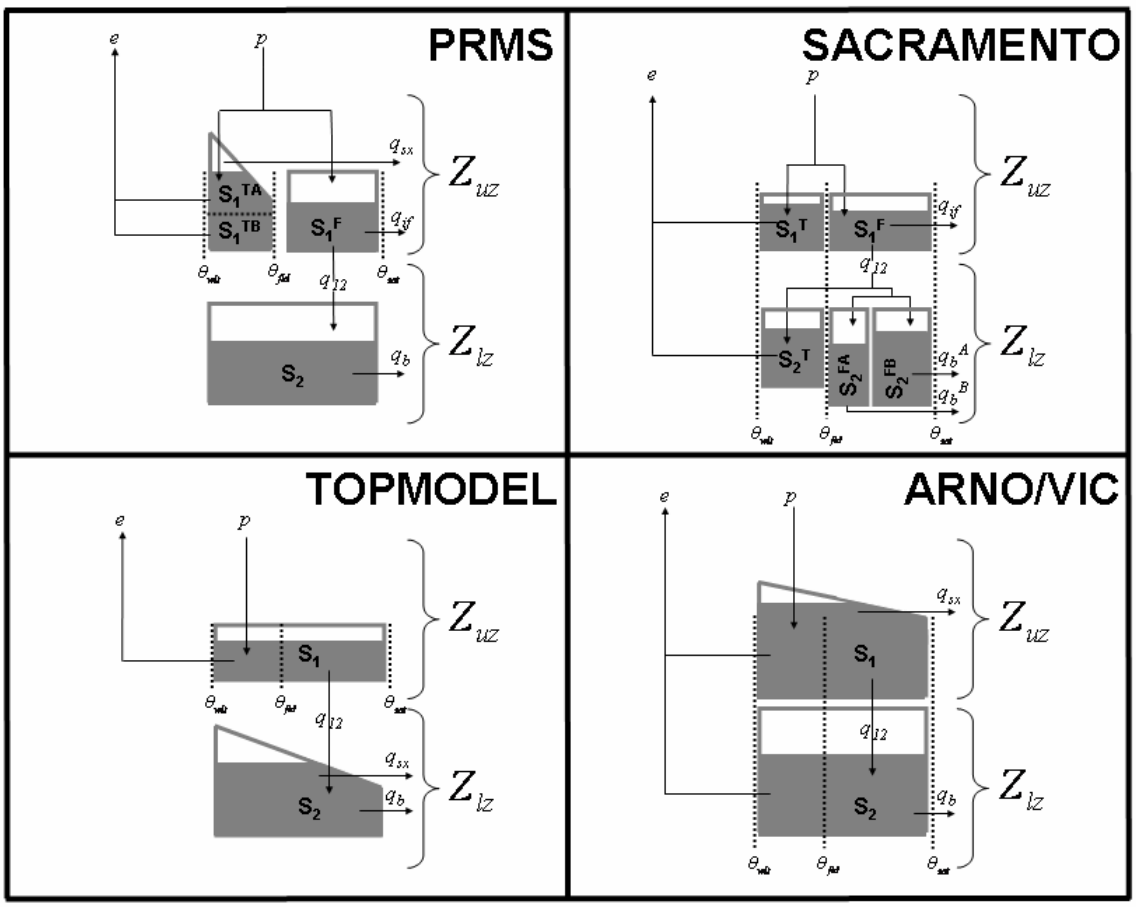
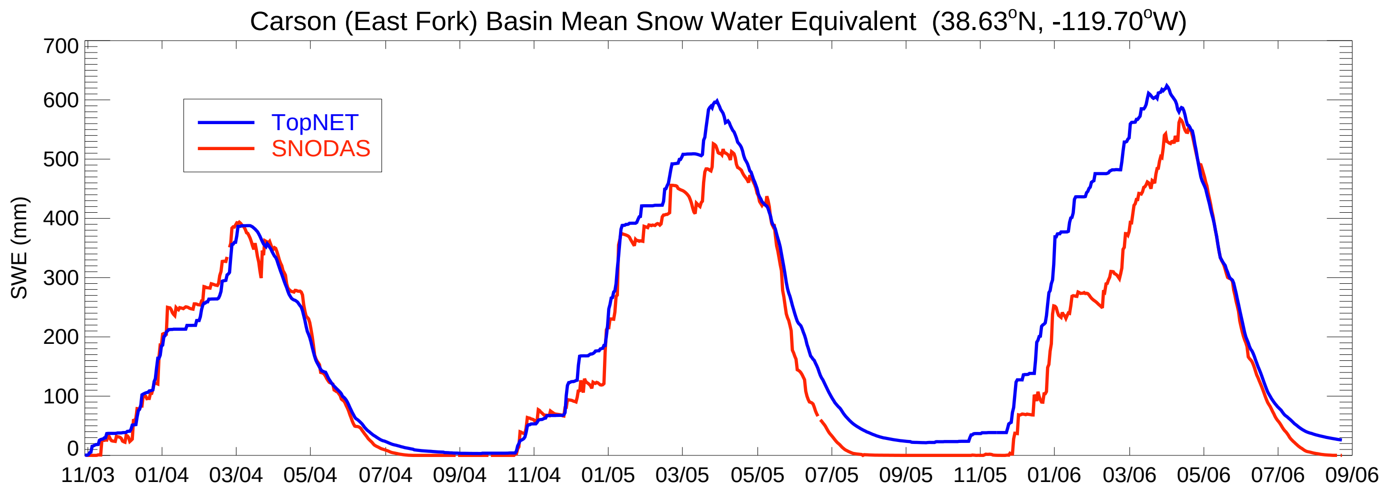


Figure 2. Wiring diagrams of the initial four models used in the model structural uncertainty assessment, indicating the "parent" model whose conceptualization the model represents. Individual sub-components of each model were combined to form 79 unique models which could share parameters of equal meaning.



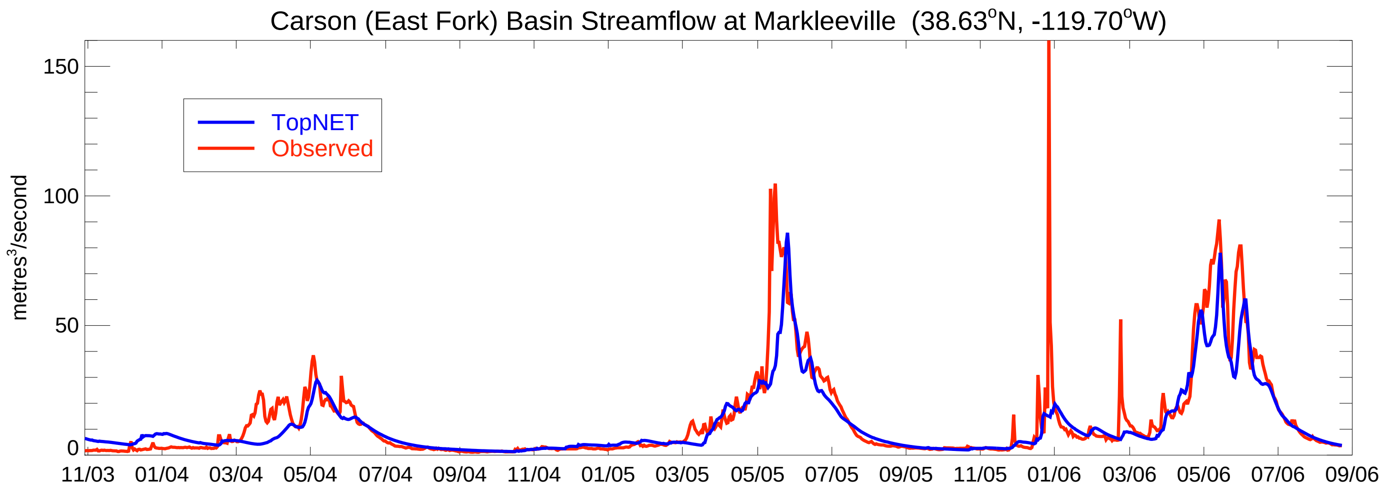


Figure 3: Results form the TopNet model when the snow simulation is calibrated against snow water equivalent from SNODAS. The model predicts more snow than SNODAS, but produces less runoff than observations, suggesting that the SNODAS product has slightly underestimated snow volume in this basin.