March 1, 2006

Dear Dr. Restrepo,

We would like to request funding for the third year of our project "Improving operational streamflow forecasts in the Colorado River Basin." This project is designed to improve the probabilistic skill of streamflow forecasts in snowmelt-dominated river basins, by both explicitly quantifying all sources of uncertainty in the hydrologic modeling process and reducing model uncertainty through assimilation of observed snow data.

In the first year of this project we developed initial tools and procedures to quantify model uncertainty and methods to use station data on snow water equivalent to update model states. Since uncertainties in hydrologic model simulations stem primarily from uncertainties in the spatial estimates of model forcing fields (especially precipitation), our first step was to develop a method for probabilistic quantitative precipitation estimation (QPE) in complex terrain (Clark and Slater, 2006). This method produces an ensemble of model forcing fields—the differences in model states (e.g., snow water equivalent) that arise when the model is run with each of the forcing ensembles provides an estimate of the model uncertainty associated with uncertainties in model inputs. For snow data assimilation we used the probabilistic QPE method to construct model ensembles, and implemented the ensemble Kalman filter to update model simulations with observed snow water equivalent data (Slater and Clark, 2006). The ensemble snow data assimilation was shown to provide substantial improvements in modeled snowpack, especially in the early part of the accumulation season and the later part of the melt season.

Our work in the second year of this project sought to extend and refine the work in year one. The problems with our methods for quantifying model error are that, in our initial work, model errors are entirely a function of uncertainty in model inputs. Clearly, uncertainties in model parameters and weaknesses in model structure are also important. However, addressing these issues entails understanding the inter-relationships between all sources of uncertainty in the modeling process. Work in this area is still underway, but Clark and Vrugt (2006) published initial results on this topic. The snow data assimilation work was extended in two ways. First, we evaluated the potential uses of satellite snow covered area information to update model states. This involved work on quantifying errors in remotely sensed fractional snow covered area products (work still underway), as well as methods to use fractional snow covered area information to update model states (Clark et al., 2006a). As a spin-off from this work, we wrote a book chapter on the scientific and societal uses of remotely sensed snow and ice information (Clark et al., 2006b). Our second research thrust in snow data assimilation has been comparing one- and three-dimensional implementations of the ensemble Kalman filter. Our initial snow data assimilation methods used a one-dimensional Kalman filter in which model updates were performed separately at each grid cell. This requires interpolated spatial fields of snow water equivalent, complete with error estimates. An alternative is the three-dimensional Kalman filter, in which observations are assimilated locally and information is propagated spatially based on the modeled spatial covariance. Work is still underway on this topic.

In the third year of this project we intend to provide methods that will allow estimates of uncertainties in all aspects of the hydrologic modeling process, as well as snow data assimilation methods suitable and ready for implementation in spatially distributed hydrologic models. Our model uncertainty work will examine the extent to which different model structures provide independent information, and the extent to which model uncertainties can be adequately quantified by ensembles of model parameters. This will necessarily involve assessing trade-offs between model parsimony and model complexity, or, more precisely, the tradeoffs between model parsimony and model completeness. Our initial work suggests that generalized hydrologic models such as the Sacramento model provide a complete depiction of hydrologic processes, and additional models do not provide any extra information that can be obtained by running the model with an ensemble of parameter sets. Our snow data assimilation work will entail completing ongoing work in quantifying errors in satellite-based snow products and comparing different implementations of the Kalman filter – the final product by the end of year three will be a comprehensive multi-observation snow data assimilation strategy that is implemented in distributed hydrologic models.

Thank you for considering this request. I hope to hear from you soon.

Sincerely,

Martyn Clark.

<u>References:</u>

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