PROGRESS REPORT FOR PROJECT NUMBER NA04NWS4620012
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TITLE: **Parameterization and Parameter Estimation of Distributed Models For Flash Flood and River Prediction**

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1. PROJECT OBJECTIVES AND ACCOMPLISHMENTS

1.1. Project Objectives

The shift from lumped to distributed models raises many important questions about the proper choice of model parameterization, including the desirable level of model complexity, while significantly increasing the complexity of the parameter estimation problem. The main objective of this project is to collaborate with and support the Hydrologic Modeling team at the NWS Office of Hydrology in the rapid development of an advanced version of the NWS-OH distributed hydrologic model, with particular attention to the issues of parameter estimation, appropriate model structure, supportable model complexity, and model evaluation, diagnosis and improvement. The unifying theme through this proposal is to focus on improving distributed watershed modeling through addressing issues of model parameterization (specification of model components), and estimation of the model parameters in both gauged and ungauged settings. The following tasks were listed under this contract:

1. Parameterization of semi-distributed and distributed hydrologic models within Hydrology Laboratory-Research Modeling System (HL-RMS) framework,
2. Distributed parameter estimation (automated and/or semi-automated) for the above (this work will build on our experience with lumped models, while introducing novel ideas such as regularization that are specifically tailored to distributed models),
3. A priori methods for parameter estimation in ungauged basins using direct inference from watershed properties and statistical regression analysis (existing work by NWS-HL staff will be extended and used to drive this important area of hydrologic modeling research forward).

This work extends our past collaborative work with the NWS by supporting the development of distributed modeling capabilities with particular attention given to ungauged and poorly gauged watersheds, consistent with the aims and future directions of the NWS. This research is being implemented in the context of the HL-RMS thereby maximizing technology transfer and ensuring that the work outcome is of direct value to the NWS.

1.2. Summary of Work Proposed for the First Year

a. Implement HL-RMS at the University of Arizona as a modeling environment. Incorporate currently available calibration algorithms.
b. Investigate and implement a distributed parameter estimation algorithm based on the concept of regularization
c. Investigate the a priori parameter estimation problem using both bottom-up (incl. the development of relationships between the parameters of the NWS conceptual model components to soil and watershed characteristics) and top-down (regionalization) approaches.
d. Technology transfer through (in person and telephone) meetings.

1.3. Project Accomplishments During Progress Report Period (01/01/2005 – 01/01/2006)

Our activities during last year focused mainly on two different but overlapping perspectives on improving streamflow predictions. We have incorporated a priori knowledge on the watershed physical properties (i.e., soil texture, land cover etc.) in parameter estimation and also we have utilized watershed input-output datasets (specifically watershed indices) within a statistical framework to constrain ensemble streamflow predictions. Details of the accomplishments are as follows:

a. The Hydrology Laboratory-Research Modeling System (HL-RMS) was linked to an automated optimization algorithm called "*Multi Objective Shuffled Complex Evolution – Metropolis Algorithm (MOSCEM)*" (Vrugt et. al, 2003) to enable optimization of multipliers of a priori hydrologic model parameter grids. (Handouts p. 8-10)

   A priori model parameter grids were estimated within the framework developed by Koren et al. (2000). Assuming that the spatial pattern of the model parameters was well defined by the a priori estimates, we optimized the multipliers of each parameter grid. Multipliers were allowed to vary within a range, so that the parameter values in a grid remained within the suggested parameter ranges defined by Koren et al. (2003). (See page 7 in handouts for details). Blue River (BLUO2) and Baron Fork River (ELDO2) were selected as test basins. Weather radar precipitation data and streamflow data available for DMIP-1 were used for model calibration at hourly time steps covering 01/10/1997 – 31/10/1998 period (1 month warm-up). Evaluation period was 01/11/1998-03/31/1999 (1 month warm-up). An objective function (FTOTAL) was selected that incorporates the fit to streamflow observations at the outlet (FDATA) and also penalizes the deviation from the a priori parameter estimates (Penalty Function - FPAR). The function FDATA was further separated into driven and non-driven streamflow segments. Heteroscedastic uncertainty associated with the streamflow observations was estimated through the use of a wavelet denoising algorithm. In the procedure, a heuristic wavelet coefficient thresholding algorithm was used to filter the hourly streamflow observations and a moving window was used to define the error variance of the streamflow observations. Changing the weights of the FDATA and FPAR in the objective function defines a multi-objective framework.

b. A study was undertaken to analyze the propagation of the uncertainty in the soil hydraulic parameters to the a priori hydrologic model parameters (Handouts p. 16-20).

A priori model parameter estimates defined by equations given in Koren et al. (2003) require estimates of soil hydraulic parameters. These soil hydraulic parameters are estimated through Pedotransfer Functions (PTFs) which relate soil texture information to the soil hydraulic parameters. One of the assumptions in these PTFs is that percentages of sand and clay in a soil texture class are defined by the center point of each class within USDA soil texture triangle. As a preliminary analysis, the uncertainty in soil texture information was estimated by randomly sampling sand and clay percentages for each soil texture class. These samples were then used subsequently within PTFs and a priori parameter equations to analyze resulting effect on the model a priori parameter values. Results suggest that given a wide sand/clay percentage variation within a soil texture class, there may be moderate changes in a priori model parameters. The resulting effect of these model parameter variations on the simulated hydrograph is an analysis scheduled for the near future.

c. A model diagnostics interface has been developed within MATLAB® environment. (Handouts p.6)

This interface uses the time series and gridded output from the HL-RMS model to build a movie file showing the time propagation of precipitation (both gridded and time series) and corresponding model responses in terms of states as well as model generated fluxes. These variables can be analyzed at a particular time step to visualize the model behavior at different parts of the basin under consideration.

d. A pilot study into the regionalization of watershed response characteristics has been performed (Yadav et al., 2006).

This included the development of a top-down framework to perform this task in an uncertainty framework and the development of a Matlab toolbox to calculate indices of hydrologic response behavior. The regionalized ranges of likely watershed responses at ungauged sites provide a constraint that can be used to reduce the number of possible parameter sets that can represent the ungauged watershed. This approach allows us to include larger scale characteristics (e.g. topography or drainage area) into the parameter estimation process at ungauged sites. This is a model independent approach that will complement the bottom-up approach discussed under point b.

2. SUMMARY OF RESEARCH AND EDUCATIONAL EXCHANGES

Scientific exchanges between UA/PSU researchers and NWS-HL personnel have taken place in the form of phone calls and e-mails. Victor Koren and Fekadu Moreda provided guidance during application of the a priori parameter estimation methodology. Also during the HL-RMS installation at UA, Victor Koren and Zhengtao Cui of HL provided guidance through timely and effective communication. Victor Koren, Zhengtao Cui and Fekadu Moreda have also provided help and guidance to set-up the HL-RMS on PSU computers. A presentation of the activities in this project to international visitors from the Slovac Meteorological Service to the International Office of the NWS was made at PSU.

3. PRESENTATIONS AND PUBLICATIONS

Hogue, T.S., Yilmaz, K., Wagener, T. and Gupta, H.V. 2006. Modeling ungauged basins with the Sacramento model. In Andréassian, V., Chahinian, N., Hall, A., Perrin, C. and Schaake, J. (eds.) Large sample basin experiments for hydrological model parameterization Results of the MOdel Parameter Experiment (MOPEX) Paris (2004) and Foz de Iguaçu (2005) workshops. IAHS Redbook. In Press.

McIntyre, N., Lee, H., Wheater, H.S., Young, A. and Wagener, T. 2005. Ensemble prediction of runoff in ungauged watersheds. *Water Resources Research*, 41, W12434, doi: 10.1029/2005WR004289.

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Wagener, T., Hogue, T., Schaake, J., Duan, Q., Gupta, H.V., Andreassian, V., Hall, A. and Leavesley, G. 2006. The Model Parameter Estimation Experiment (MOPEX): Its structure, connection to other international initiatives and future directions. In Andréassian, V., Chahinian, N., Hall, A., Perrin, C. and Schaake, J. (eds.) Large sample basin experiments for hydrological model parameterization Results of the MOdel Parameter Estimation Experiment (MOPEX) Paris (2004) and Foz de Iguaçu (2005) workshops. IAHS Redbook. In Press.

Yadav, M., Wagener, T. and Gupta, H.V. 2006. Regionalization of dynamic watershed behavior. In Andréassian, V., Chahinian, N., Hall, A., Perrin, C. and Schaake, J. (eds.) Large sample basin experiments for hydrological model parameterization Results of the MOdel Parameter Estimation Experiment (MOPEX) Paris (2004) and Foz de Iguaçu (2005) workshops. IAHS Redbook. In Press.

Yilmaz, K., Hogue, T.S., Hsu, K.-L., Sorooshian, S., Gupta, H.V. and Wagener, T. 2005. Evaluation of rain gauge, radar and satellite-based precipitation estimates with emphasis on hydrologic forecasting. *Journal of Hydrometeorology*. 6(4), 497–517.

Yilmaz, K., Hogue, T.S., Hsu, K.-L., Sorooshian, S., Gupta, H.V. and Wagener, T. 2005. Evaluating the Utility of Satellite-based precipitation estimates for flood forecasting in ungauged basins. In Wagener, T., Franks, S., Gupta, H.V., Bogh, E., Bastidas, L., Nobre, C., Galvao, C. (eds.) Regional Hydrological Impacts of Climatic Change – Impact Assessment and Decision Making. IAHS Redbook, Publication No. 295, 273-282.

4. FUTURE WORK

In the light of the experience we have gathered from the above analysis, the following studies will be performed:

a) Parallel processing techniques will be investigated for faster model runs required by the optimization algorithm.

b) Improved handling of the multipliers will be analyzed. Current methodology is has shown to be sensitive to outliers in the parameter grid values. Clustering analysis and non-linear transformations will be studied.

c) Watershed physical characteristics will be utilized for model parameterization (i.e. regularization) and model structure identification.

d) Uncertainty in the soil texture information will be estimated through uncertainties in pedotransfer equations in addition to the currently employed sand/clay percentage uncertainties.

e) Other sources of uncertainties (such as input and model structure) will be investigated.

f) Finalizing the regionalization of response characteristics framework. Missing aspects are for example, how to evaluate ensemble predictions at ungauged sites, test of implication of regression assumptions, etc.

g) Connecting the bottom-up and top-down approaches discussed above to a single procedure.

5. SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

Benefits that have been experienced during the last year

a. UA/PSU researchers are becoming familiar with the prototype distributed hydrologic model for real time forecasting developed by NWS-HL in an effort to contribute and share new ideas. Students are becoming familiar with NWS software, methods and procedures.
b. Fruitful communication between UA/PSU researchers and HL personnel has continued.

Problems encountered

a. No significant problems were encountered during the last 6 months.

6. REFERENCES

Koren, V. I., Smith, M., Wang, D. and Zhang, Z. (2000). Use of soil property data in the derivation of conceptual rainfall-runoff model parameters. 15th Conference on Hydrology, Long Beach, American Meteorological Society, Paper 2.16, USA.

Koren, V., Smith, M. and Duan, Q. (2003). Use of a priori estimates in the derivation of spatially consistent parameter sets of rainfall-runoff models. In Duan, Q., Gupta, H.V., Sorooshian, S., Rousseau, A.N. and Turcotte, R. (eds.) *Calibration of watershed models*. American Geophysical Union, Water Science and Application, Vol. 6, Washington, pp. 239-254.

Vrugt J. A., H. V. Gupta, L. A. Bastidas, W. Bouten, S. Sorooshian, 2003. Effective and efficient algorithm for multiobjective optimization of hydrologic models, Water Resour. Res., 39 (8), 1214, doi:10.1029/2002WR001746.