PROGRESS REPORT FOR PROJECT NUMBER NA04NWS4620012
Covers the Period 12/01/06 TO 05/31/2007
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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

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. Testing of various modifications of the HL-RMS including the comparison to semi-arid specific models.
e. Combining the research on a priori and distributed parameter estimation into a single procedure.
f. Testing the basic equations relating model parameters and watershed properties in a multi-watershed study. Complementing this approach with a statistical regionalisation approach using a minimum of 30 watersheds.
g. Implementing and testing various ensemble-forecasting schemes.
h. Technology transfer through (in person and telephone) meetings.
i. Implementing and testing the new tools for a priori and distributed parameter estimation into the HL-RMS.
j. Extending the Bayesian recursive scheme from lumped to distributed model structures.
k. Continue work on ensemble forecasting schemes.
l. Technology transfer through (in person and telephone) meetings.

1.3. Project Accomplishments During Progress Report Period (12/01/2006 - 05/31/2007)

Our activities during last six months focused on: a) improving the strategy for diagnostic evaluation of HL-DHMS model, b) extending the regionalization approach introduced by Yadav et al. (2007) to identify behavioral parameter sets.

a) *The diagnostic model evaluation strategy was extended to detect streamflow timing errors in the HL-DHMS model predictions.*

The HL-DHMS model parameterized by Koren a priori parameterization scheme (Koren et al., 2000) was used as a baseline model to benchmark the model performance improvements obtained by diagnostic model evaluation strategy. Upon reviewing the timing measures commonly used in the hydrologic literature, two flow timing measures were formulated: an event-based measure and an overall time period measure. Event-based measure is based on isolating representative flow events from a hydrograph. Each flow event is then partitioned into rising and falling segments and time location of flow

centroid is calculated for each segment. One-at-a-time and random sampling based parameter perturbations were performed to isolate the parameters affecting the time location of simulated flow centroid of the rising limb (signature measure for flow timing). Overall, the perturbation analysis results revealed that UZFWM and ROUTQ0 (specific discharge parameter of the channel routing model) are the dominant parameters controlling the timing of flow in HL-DHMS model. Note that all routing model parameters, except ROUTQ0, were fixed at their a priori values. Another timing measure based on processing of rainfall (mean areal rainfall) and streamflow observations for overall time period was formulated. The goal was to estimate, in a simple way, the intrinsic time-lag of the watershed. In the procedure, the time-shift (hours) providing the maximum correlation between mean areal rainfall and streamflow time series was selected as time-lag of the watershed. In this manner, time-lag can be calculated for flows above a threshold value. Parameter perturbation analysis revealed that UZFWM and ROUTQ0 are the dominant parameters controlling time-lag of the watershed, and hence supported the findings from event-based flow timing analysis. Future work will focus on HL-DHMS model deficiencies caused by incorrect spatial distribution of parameters.

b) *The new regionalization approach introduced by Yadav et al. (2007) was extended to include a global multi-objective optimization approach to identify behavioral parameter sets.*

Yadav et al. (2007) showed that regionalized indices of watershed response characteristics (e.g. runoff ratio) can be used to considerably reduce the uncertainty in ensemble streamflow predictions at ungauged locations. Indices of hydrologic response were regressed against physical and climatic watershed characteristics including uncertainty. The regression thus provides ranges for response indices at ungauged locations and models (parameter sets) not producing indices within these ranges can be eliminated as unacceptable from ensemble forecasts. One drawback of the proposed strategy was, however, that a very inefficient Monte Carlo approach was used to identify acceptable parameter sets. This limited the approach to very few indices that could be used simultaneously, and to simple watershed model structures. We recently reformulated the problem of finding acceptable parameter sets as a multi-objective optimization problem and solved it using a evolutionary genetic algorithm. Running the algorithm on a parallel cluster, we showed that for 30,000 function evaluations a relatively consistent population of about 10,000 acceptable parameter sets could be found. This improvement to the approach will now allow us to test it on spatially explicit watershed models such as the HL-DHMS.

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. The research performed for this project was incorporated into the DMIP-2 experiment organized by the NWS Hydrology Laboratory. Victor Koren, Mike Smith and Zhengtao Cui of HL provided technical assistance for HL-DHMS model.

3. PRESENTATIONS AND PUBLICATIONS

Pokhrel, P, Estimation of Spatially Distributed Model Parameters Using a Regularization Approach, MS Thesis, Univ. of Arizona, April 2007.

Reed, P.M., Tang, Y., *Werkhoven, K. van and Wagener, T. 2007. Using Global Sensitivity Analysis to Better Understand How Real-Time Observations Influence Operational Flood Forecasts in the Susquehanna River Basin. ASCE World Water and Environmental Resources Congress, Tampa, Florida, May 2007. (Oral)

Reed, P.M., Tang, Y., Van Werkhoven, K. and Wagener, T. 2007. Using global sensitivity analysis to better understand how real-time observations influence operational flood forecasts in the Susquehanna River Basin. Association of Environmental Engineering and Science Professors, Blacksburg, Virginia July 2007. (Poster)

Tang, Y., Reed, P., Van Werkhoven, K. and Wagener, T. 2007. Advancing the identification and evaluation of distributed rainfall-runoff models using global sensitivity analysis. *Water Resources Research*, 43, doi:10.1029/2006WR005813.

Tang, Y., Reed, P., Wagener, T. and Van Werkhoven, K. 2007. Comparing sensitivity analysis methods to advance lumped watershed model identification and evaluation. *Hydrology and Earth System Sciences*, 11, 793-817.

Van Werkhoeven, K., Wagener, T., Reed, P. and Tang, Y. 2007. Sensitivity analysis of a distributed hydrologic model for uncertainty reduction and identification of dominant model controls. 14th IUGG General Assembly, Perugia, Italy, 2-13th July 2007. (Poster)

Van Werkhoven, K., Wagener, T., Tang, Y., and Reed, P. Understanding watershed model behavior across hydro-climatic gradients using global sensitivity analysis. *Water Resources Research*. (Pending Minor Revisions)

Wagener, T., Gupta, H.V., Yilmaz, K. and Yadav, M. 2007. Evaluation of hydrologic models in ungauged basins using regionalized watershed response characteristics. 14th IUGG General Assembly, Perugia, Italy, 2-13th July 2007. (Oral)

Wagener, T., Reed, P., *Werkhoven, K. van and Tang, Y. 2007. Identification and evaluation of complex environmental systems models using global sensitivity analysis and evolutionary multiobjective optimization. International Workshop on Advances in Hydroinformatics (HIW07), Niagara Falls, Canada, June 4-7th 2007. (Invited Keynote)

Yadav, M., Wagener, T. and Gupta, H.V. 2007. Regionalization of constraints on expected watershed response behavior for improved predictions in ungauged

basins. *Advances in Water Resources*, 30(8), 1756-1774. doi:10.1016/j.advwatres.2007.01.005.

Yilmaz, K., and H.V. Gupta, Towards improved modeling for ungauged and poorly gauged basins: Presented at Middle East Technical University, Ankara, Turkey, June 29, 2007 (Invited Talk)

Yilmaz, K., H.V. Gupta and T. Wagener, Diagnostic Evaluation of a Distributed Watershed Model: A Process-based Approach, Presented at the IUGG General Assembly, Perugia, Italy, July 9–13, 2007 (Oral)

Yilmaz, K., K., 2007. Towards improved modeling for hydrologic predictions in poorly gauged basins, Ph.D. Dissertation, Univ. of Arizona.

4. FUTURE WORK

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

a) Measures that are powerful in diagnosing HL-DHMS model inadequacies will be further researched.

b) Parallel processing techniques developed at the Penn State University will be implemented at the University of Arizona to perform faster model runs required by the optimization algorithms.

c) Implementation of regionalization approach in US watersheds.

d) Connecting sensitivity analysis and model calibration in combined 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 HL-DHMS distributed hydrologic model developed by NWS-HL in an effort to contribute and share new ideas. Students are becoming familiar with NWS software, methods and procedures.

b. Project provided research subjects for two master theses (Prafulla Pokhrel, Univ. of Arizona & Maitreya Yadav, PSU) and in part a Ph.D. dissertation (Koray K. Yilmaz, Univ. of Arizona). Sub-projects have been derived from this project for

elements of the PhD dissertations by Yong Tang and Katie van Werkhoven (PSU).

c. 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.