PROGRESS REPORT FOR PROJECT NUMBER NA04NWS4620012
Covers the Period 12/01/07 TO 05/31/08
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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 & SUMMARY OF WORK PROPOSED

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 our work 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 are listed under this contract:

1. Parameterization of semi-distributed and distributed hydrologic models within Hydrology Laboratory-Distributed Hydrologic Model (HL-DHM) 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 will extend 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 will be implemented in the context of the HL-DHM 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-DHM 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. Combine the research on a priori and distributed parameter estimation into a single procedure.
e. Test the basic equations relating model parameters and watershed properties in a multi-watershed study. Complement this approach with a statistical regionalisation approach using a minimum of 30 watersheds.
f. Implement and test the new tools for a priori and distributed parameter estimation into the HL-DHM.
g. Technology transfer through (in person and telephone) meetings.

2. PROJECT ACCOMPLISHMENTS DURING THE PERIOD 12/01/2007 – 05/31/2008

Our activities during this period focused on preparation of the journal articles related to findings from this project,

a) The Diagnostic Evaluation approach has been reported in Hydrological Processes and Water Resources Research (Gupta et al, 2008, Yilmaz et al 2008a).

b) The Multi-criteria Penalty Function Approach has been extended to include non-linear multipliers on the spatially distributed model parameters (Yilmaz et al., 2008a) and reported in Advances in Water Resources (Yilmaz et al 2008b in review).

a) The Spatial Regularization Approach has been reported in Water Resources Research (Pokhrel et al 2007 in review).

b) The results from the Diagnostic Evaluation Approach and the Spatial Regularization Approach have been submitted to the DMIP-2 experiment organized by Hydrology Laboratory of the NWS.

c) The regionalization work has been reported in Advances in Water Resources and in Water Resources Research (Yadav et al. 2007; Zhang et al. 2008).

d) The use of sensitivity analysis to advance in lumped and distributed hydrological modeling has been reported in Water Resources Research, Geophysical Research Letters and Advances in Water Resources. (Tang et al. 2007a, b; van Werkhoven et al. 2008a, b, c; Wagener et al., 2008).

3. SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

Benefits:

a. UA/PSU researchers are became familiar with the distributed hydrologic model for real time forecasting developed by NWS-HL in an effort to contribute and share new ideas. Students and researchers became familiar with NWS software, methods and procedures.
b. Fruitful communication between UA/PSU researchers and HL personnel significantly improved the outcome of the project.
c. The project enabled UA researchers to participate actively in the NWS run DMIP and DMIP-2 projects.

Problems encountered:

a. No significant problems have been encountered during the reporting period.

4. PUBLICATIONS AND PRESENTATIONS

4.1. Refereed Journal Articles

Gupta, H. V., T. Wagener and Y. Liu, Reconciling Theory with Observations: Towards a Diagnostic Approach to Model Evaluation, *Hydrological Processes*, 2008. DOI: 10.1002/hyp.6989.

Pokhrel, P., H.V. Gupta, and T. Wagener, A Spatial Regularization Approach to Parameter Estimation for a Distributed Watershed Model, *Water Resources Research*, in 2nd review 2008.

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

Van Werkhoven, K., Wagener, T., Reed, P. and Tang, Y. 2008a. Rainfall characteristics define the value of streamflow observations for distributed watershed model identification. *Geophysical Research Letters*, 35, L11403, doi:10.1029/2008GL034162.

Van Werkhoven, K., Wagener, T., Reed, P. and Tang, Y. 2008b. Characterization of watershed model behavior across a hydroclimatic gradient. *Water Resources Research*, 44, doi:10.1029/2007WR006271.

Van Werkhoven, K., Wagener, T., Tang, Y., and Reed, P. 2008c. Complexity reduction in multiobjective watershed model calibration. *Advances in Water Resources*, (In Review).

Wagener, T., Reed, P., Van Werkhoven, K., Tang, Y. and Zhang, Z. Advances in the identification and evaluation of complex environmental system models. *Journal of Hydroinformatics*, Invited Paper. (In Review)

Yadav, M., T. Wagener, and H.V. Gupta, 2007. Regionalization Of Constraints On Expected Watershed Response Behavior For Improved Predictions In Ungauged Basins, *Advances in Water Resources*, *Advances in Water Resources*, 30(8) pp. 1756-1774, doi:10.1016/j.advwatres.2007.01.005

Yilmaz, K. K., H.V. Gupta, and T. Wagener, A Process-Based Diagnostic Approach to Model Evaluation: Application to the NWS Distributed Hydrologic Model, *Water Resources Research*, In press 2008a.

Yilmaz, K., Gupta, H.V. and T. Wagener, Evaluating the A Priori Parameters of the HL-DHM Model using a Multi-criteria Penalty Function Approach, *Advances in Water Resources*, in review 2008b.

Zhang, Z., Wagener, T., Reed, P. and Bhushan, R. 2008. Ensemble streamflow predictions in ungauged basins combining regionalized streamflow indices and multiobjective optimization. *Water Resources Research*. (In Press)

4.2. Keynote Lectures and Invited Presentations

Gupta, H.V., Reconciling Theory with Observations: Elements of a Diagnostic Approach to Model Evaluation, Presentation (Invited) at Imperial College, London, UK, Feb 7, 2008.

Gupta, H.V., Reconciling Theory with Observations: Elements of a Diagnostic Approach to Model Evaluation, Presentation (Invited) at Department of Hydrology and Water resources, The University of Arizona, Apr 2, 2008.

Wagener, T. 2008. Catchment similarity and its utility for scientific investigation and operational predictions. UNESCO Workshop on Comparative analysis of floods and droughts - Catchment and aquifer typology, 20-23rd April 2008, Smolenice near Bratislava, Slovakia. (Invited Talk)

Wagener, T., Sivapalan, M., Troch, P. and Woods, R. 2008. Searching for a catchment classification system for hydrology. 2008 Assembly of the European Geosciences Union (EGU), 13-18th April 2008, Vienna, Austria. (Invited Talk)

4.3. Presentations

Gupta, H.V., T. Wagener, K. Yilmaz, P. Pokhrel, H. Kling, Parameterization And Parameter Estimation Of Distributed Models For Flash Flood And River Prediction. Presentation at the NWS Office of Hydrology, Feb 28, 2008.

Kling, H., K. Yilmaz and H.V. Gupta, Diagnostic Evaluation of a Distributed Precipitation-Runoff Model for Snow Dominated Basins, presented at the

American Geophysical Union: Joint Assembly, 27th to 30th May 2008, Fort Lauderdale, FL, USA, 2008.

Kling, H., and H. V. Gupta, Relationship between spatial discretization and the parameters and model performance of precipitation-runoff and water balance models, Presented at the Fall Meeting of the American Geophysical Union, H18: Parameter Estimation in Hydrology: Theoretical Developments and Applications, San Francisco, CA, USA, Dec 10-17, 2007.

Pokhrel, P., H.V. Gupta, H.V., and Wagener, T., Distributed Parameter Estimation Using a Regularization Approach, presented at El Dia Del Agua, Department of Hydrology & Water Resources, The University of Arizona, Tucson, Arizona, Mar 6, 2008.

Rosero, E., Gulden, L.E., Yang, Z.-L., Gochis, D.J., Wagener, T. and Niu, G.-Y. 2008. Identifying a good LSM: Use of a new, ensemble-based framework to evaluate enhanced hydrological representations in the NOAH land surface model. AGU Joint Assembly, 27-30th May 2008, Fort Lauderdale, Florida, USA.

Tang, Y., Reed, P., *Van Werkhoven, K. and Wagener, T. 2008. Comparison of parameter sensitivity analysis methods for lumped watershed models. World Environmental & Water Resources Congress - American Society of Civil Engineers EWRI Section, 12-16th May 2008, Hawaii, USA.

Van Werkhoven, K. and Wagener, T. 2008. Reducing uncertainty in hydrologic predictions in data sparse regions: A case study in southern Africa. 88th American Meteorological Society Annual Meeting, 20-24th January 2008, New Orleans, USA.

Van Werkhoven, K., Wagener, T., Reed, P. and Tang, Y. 2007. Characterization of watershed model behavior and sensitivity-guided parameter optimization across a hydroclimatic gradient. AGU Fall Meeting, 10-14th December 2007, San Francisco, USA.

Wagener, T., R. Bhushan, P. Reed, H. V. Gupta, M. Yadav, and Z. Zhang, A new approach to the calibration of complex watershed models in ungauged basins using regionalized hydrologic indices. Presented at the Fall Meeting of the American Geophysical Union, H18: Parameter Estimation in Hydrology: Theoretical Developments and Applications, San Francisco, CA, USA, Dec 10-17, 2007.

Yilmaz, K.K., Gupta, H.V., Wagener, T., 2008: Evaluating the utility of satellite-based precipitation estimates for flood forecasting in ungauged basins, Poster presented at Seventh Annual AMS Student Conference, 19-20 January, New Orleans, LA, 2008

Yilmaz, K.K., Gupta, H.V., Wagener, T., A Signature Index Approach To Diagnostic Evaluation And Parameter Estimation Of Watershed Models, presentation at HydroPredict 2008 conference, Prague, Czech Republic, Sept 15-18, 2008.

Yilmaz, K.K., H.V. Gupta, and T. Wagener, A signature index approach to diagnostic evaluation and parameter estimation of watershed models, Poster Presented at the Fall Meeting of the American Geophysical Union, H18: Parameter Estimation in Hydrology: Theoretical Developments and Applications, San Francisco, CA, USA, Dec 10-17, 2007.