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The Model Parameter Estimation Experiment (MOPEX): Its structure, connection to other international initiatives and future directions

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Abstract. The Model Parameter Estimation Experiment (MOPEX) is an international project aimed at developing enhanced techniques for the a priori estimation of parameters in hydrologic models and in land surface parameterization schemes connected to atmospheric models. The MOPEX science strategy involves: database creation, a priori parameter estimation methodology development, parameter refinement or calibration, and the demonstration of parameter transferability. A comprehensive MOPEX database has been developed that contains historical hydrometeorological data and land surface characteristics data for many hydrologic basins in the United States (US) and in other countries. This database is being continuously expanded to include basins from various hydroclimatic regimes throughout the world. MOPEX research has largely been driven by a series of international workshops that have brought interested hydrologists and land surface modelers together to exchange knowledge and experience in developing and applying parameter estimation techniques. With its focus on parameter estimation, MOPEX plays an important role in the international context of other initiatives such as GEWEX, PUB and PILPS. This paper outlines the MOPEX initiative, discusses its role in the scientific community and briefly states future directions.

Keywords. Hydrologic Models; Parameters; Calibration; A Priori; Transferability; Regionalization; Uncertainty

INTRODUCTION

Hydrologic and land surface models are tools of increasing importance for water resources management world-wide. Particularly important are modeling activities to

support decision making in the context of strategic planning for potential climate and land use change in basins and its impact on water resources. Requirements to successfully perform these modeling tasks are that we can reliably model a wide range of hydroclimatic regimes and understand how changes in the watershed are reflected in changes in the model parameters or its structure. Current model structure requires that at least some key parameters are adjusted according to the fit of the model predictions to observations of the response variable of interest (usually streamflow), a process called calibration. However, these measurements are not always available and other approaches to derive a priori (before calibration) parameter estimates are needed. Current procedures for a priori parameter estimation are often based on relationships between model parameters and basin characteristics— that is, soils, vegetation, topography, climate, geology, etc. These developed relationships have not been fully validated through rigorous testing using retrospective hydrometeorological data and corresponding land surface characteristics. This is partly because the necessary database needed for such testing has not been available. Moreover, there still exists a gap in our understanding of the links between model parameters and land surface characteristics. Generally, available information about soils and vegetation typically only indirectly relates to model parameters that conceptualize aspects such as the hydraulic properties of soils and rooting depths of vegetation. It is also not clear how heterogeneity associated with spatial land surface properties affects those characteristics at the scale of a basin or a grid cell. Consequently, there is a considerable degree of uncertainty associated with the parameters derived using current procedures, which is propagated into the model predictions and into the subsequent decision making process.

The Model Parameter Estimation Experiment (MOPEX) is an ongoing international project to help develop techniques for the a priori estimation of parameters used in land surface parameterization schemes of atmospheric and hydrological models. MOPEX is affiliated with both the Prediction in Ungauged Basins (PUBS) and the Global Energy and Water Cycle Experiment (GEWEX), and is supported by the GEWEX American Prediction Project (GAPP) as well as by individual participants. MOPEX evolved to address the parameter estimation problem and to promote and guide the development of improved a priori parameter techniques applicable to both gauged and ungauged basins. The MOPEX project has been an international collaborative effort since 1996, with the involvement of international scientists and data sets assembled from different countries.

The scope of this paper includes an outline of the MOPEX initiative, a discussion of its role in the scientific community and closes with a statement of future directions.

MOPEX SCIENCE STRATEGY

The MOPEX science strategy involves three major steps (Fig. 1 figure from EOS??):

1. To develop the necessary data sets from a range of hydroclimatic regimes. The MOPEX database development strategy is outlined in the following section.
2. To use these data to develop a priori parameter estimation methodology.
3. To develop new a priori techniques and demonstrate that they produce better model results than existing a priori methods (a bit confusing here…)

Figure 1 outlines the three-path strategy for the second step in the MOPEX science strategy. The benchmark for any development is a priori parameter estimation made with currently available techniques (path 1). Any newly developed technique has to improve on this benchmark. The second path includes the calibration of the model parameters against observations of the variable of interest. These parameter estimates therefore provide the optimal (at least from an optimization point of view, not necessarily from a hydrologic point of view) parameter estimates for the basin under investigation. So, while path 1 provides the lower bound of performance that any a priori parameter estimation method has to achieve, path 2 provides the upper bound since it is (or at least should be) infeasible that any a priori estimates perform better than optimized parameters. Within the second path, the calibrated parameters are analyzed to improve our understanding of relationships between model parameters and basin characteristics (i.e. climate, soils, vegetation and topographic features). This improved understanding can then be used to derive new methods and to make new model runs in the third path. The success of step two is measured by how much improvement in model performance is achieved in the third path compared with results from the benchmark runs in the first path.

A range of objectives has been defined by the MOPEX participants over the years in order to foster the research and activities required to achieve improved a priori estimates. These can be listed as follows,

Objective 1:	To develop improved model parameter estimation techniques for ungauged basins
Objective 2:	To develop an international database of retrospective hydrometeorological data and basin characteristics data for a wide of climate and geophysiological conditions
Objective 3:	To develop objective measures to evaluate the parameter estimate techniques and to understand parameter uncertainty
Objective 4:	To develop diagnostic tools to foster improved understanding of natural hydrologic processes at basin scales and related behavior of hydrologic models
Objective 5:	To promote and facilitate the exchange of ideas and experiences on approaches to model parameter estimation for different climatic regimes

MOPEX DATABASE

Part of the implementation strategy of MOPEX is the compilation of an international database of high quality hydrometeorologic and land surface characteristic data for a wide range of Intermediate Scale Area (ISA) river basins (500–10,000 km^2) throughout the world. MOPEX has already assembled retrospective hydrometeorological data and basin characteristics data for many US basins. Data for select basins from other countries such as Australia, France, UK, Germany, and China have also been collected. Requirements for basin data sets to be included in the databases are as follows:

- The basin should be unregulated.

- The minimum hydrometeorological data required are daily precipitation, daily maximum and minimum temperature, daily streamflow data and climatic potential evaporation data.
- In an effort to ensure sufficiently high quality precipitation data, Schaake et al. (2000) have established a minimum density requirement for raingauges based on basin size that has to be fulfilled.
- A data length of at least 10 years is required to ensure various hydrologic events/periods are represented in the hydrometeorological data.
- Basic required land surface characteristics data include basin boundary, soil texture and vegetation type..

It is of course desirable to have additional data for each basin. This could be as follows,

- With respect to the hydrometeorological data: hourly surface meteorological data, including precipitation, incoming long-wave and short-wave radiation, air temperature, air humidity, atmospheric pressure, and wind speed, etc. A desirable record length would be 20 years or more.
- With respect to the land surface data: high resolution (1 km or finer) Digital Elevation Model (DEM) data, seasonal land cover/land use data such as Normalized Deviation of Vegetation Index (NDVI), greenness fraction, snow cover and soil moisture climatology, etc.

The current database is available at ftp://hydrology.nws.noaa.gov/pub/gcip/mopex. Further details regarding its content are provided by Duan et al. (in press).

MOPEX WORKSHOPS

MOPEX participants have organized a series of workshops (Table 1)as one of the main instruments in advancing MOPEX science. Workshops, which started in 1999, have been held each of the past 3 years to investigate various issues related to parameter estimation and regional model applications. The main goal of these workshops has been to test some of the MOPEX science strategies using various hydrologic and land surface models on long-term hydrometeorological data. Details of past and currently planned workshops are given in Table 1. Past workshops centered particularly around the following questions,

- How do we define the relations between model parameters and basin characteristics?
- How can model calibration be used to refine the a priori parameters?
- How do we evaluate the uncertainty due to model structure, calibration data and model parameters?

While the preceding workshops have been very successful, it was felt that a more concentrated effort is required to increase the science output derived from cooperative efforts of the workshop participants. Starting with the 2004 workshop in France, workshops will be based on a new format with the following underlying principles:

- Each workshop will have a specific focus, either in terms of hydro-climatic region (for example, humid or semi-arid) or in terms of a specific application (for example, flood forecasting).

- Each workshop will allow different levels of participation; that is, different numbers of basins that have to be simulated, to enable every participant to contribute to the collaborative science investigation. A minimum number of basins will be specified that each participant has to simulate in order to take part in the workshop. A larger number of basins is available for those who want to contribute more.
- The data sets of 12 basins from each workshop will be archived to create a database of benchmark basins that will be taken forward in time and used for comparison studies.
- This benchmark database is in addition to the general MOPEX database, which is aimed at creating a high-quality, historical hydrometeorological and river basin characteristic data sets for a wide range of Intermediate Scale Area (ISA) river basins (500–10,000 km^2) throughout the world. High-quality data sets have been obtained for Australia from the University of Melbourne and for the United Kingdom from the Institute of Hydrology, in addition to a large number of U.S. data sets.
- A small, but well-defined set of science objectives will be listed for each workshop to allow for a coordinated and meaningful analysis of workshop results.

INTERNATIONAL INITIATIVES AND THEIR RELATION TO MOPEX

The MOPEX initiative has its place in the international arena of initiatives, with its clear focus on improving parameters for hydrologic and land surface models. Here we discuss briefly how MOPEX relates to some of the main initiatives.

The Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) has revealed widely discrepant simulation results by different land surface schemes. Interestingly, the land surface schemes included in the PILPS experiments were driven by the same meteorological forcing data and were required to use the same values for commonly named parameters (such as soil hydraulic properties and vegetation phenology parameters). The large scattering of model results can be partially explained by the uncertainty in the values of the parameters used in each scheme. Development of enhanced a priori parameter estimation methodologies is therefore necessary to improve the performance of hydrologic models and land surface schemes.

MOPEX has the endorsement of several international organizations and projects including: the World Meteorological Organization (WMO) Commission on Hydrology, International Association of Hydrological Sciences (IAHS) Prediction for Ungauged Basins (PUB) Initiative (Sivapalan, 2003; Wagener et al., 2004) and the Global Energy and Water Cycle Experiment (GEWEX). The Office of Global Programs in the National Oceanic and Atmospheric Administration (NOAA) and funding agencies in different countries have all provided financial support for scientists to participate in MOPEX activities.

The Hydrologic Ensemble Prediction Experiment (HEPEX) focuses on bringing meteorological and hydrological scientists from research, operational and user communities together to work on advancing probabilistic hydrologic forecasting (Franz et al., 2005). The HEPEX initiative was launched in the spring of 2004. With it focus on

connecting the hydrological and meteorological communities, and with a strong emphasis on prediction, this initiative nicely complements MOPEX, which is focusing on parameterizing the terrestrial components of the overall modeling system.

Within the Predictions in Ungauged Basins (PUB) initiative of IAHS, MOPEX has an important position as the working group that focuses on the problems of parameter estimation in gauged and ungauged locations. It has therefore a central role and the MOPEX database is likely to be of great value within PUB where comparison studies are a major component.

LESSONS LEARNED SO FAR AND FUTURE OUTLOOK

Ultimately, models are (by definition) simplified representations of the real world and as such imperfect. This means that their parameters are also simplified representations of the real world characteristics they represent and we will therefore never find a 1:1 correlation between model parameters and basin characteristics. It is likely that there will remain some dependency on fitting the model to our intended real-world application considering the model purpose, data availability, hydro-climatic region etc. This also means that there will always be some degree of uncertainty that has to be considered in this process and that has to be communicated to any decision maker. How to estimate and represent this uncertainty in the context of imperfect models is still unclear.

Results of the MOPEX initiative so far have recently been summarized by Duan et al. (in press) as follows:

- Study results confirm earlier statements that the existing a priori parameter estimation procedures are problematic and are in need of improvement. This means that there is still large uncertainty regarding how parameter values would change under altered conditions.
- Calibration results clearly demonstrate the potential for improvement in a priori parameter estimation. The difference between the benchmark and optimized modeling results shows that there is still a clear need for calibration to be included in modeling studies and that it should be possible to improve currently available a priori approaches.
- Different models seem to represent hydrologic processes differently and all of them are imperfect. This means that parameters will in most cases be model dependent, even if they have the same name and units. Understanding this model dependence should help understanding what level of correlation between model parameters and basin characteristics can be expected.

The next workshop is planned for 2007 as part of the IAHS Peruggia meeting (Table 1).

More information about the project is available at http://www.seas.ucla.edu/~thogue/MOPEX/. A project description was published in EOS (Hogue et al., 2004).

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Table 1. MOPEX workshops.

Date	Location	Sponsor
Past		
1999	Birmingham, U.K.	IAHS[1]
2001	Maastricht, NL	IAHS
2002	Tucson, USA	NSF STC SAHRA[2]
2003	Sapporo, Japan	IAHS
2004	Paris, France	CEMAGREF
2005	Foz do Iguassu, Brazil	IAHS
Future		
2007	Perugia, Italy	IAHS

[1]International Association of Hydrological Sciences
[2]National Science Foundation Science and Technology Center for Sustainability of semi-Arid Hydrology and Riparian Areas

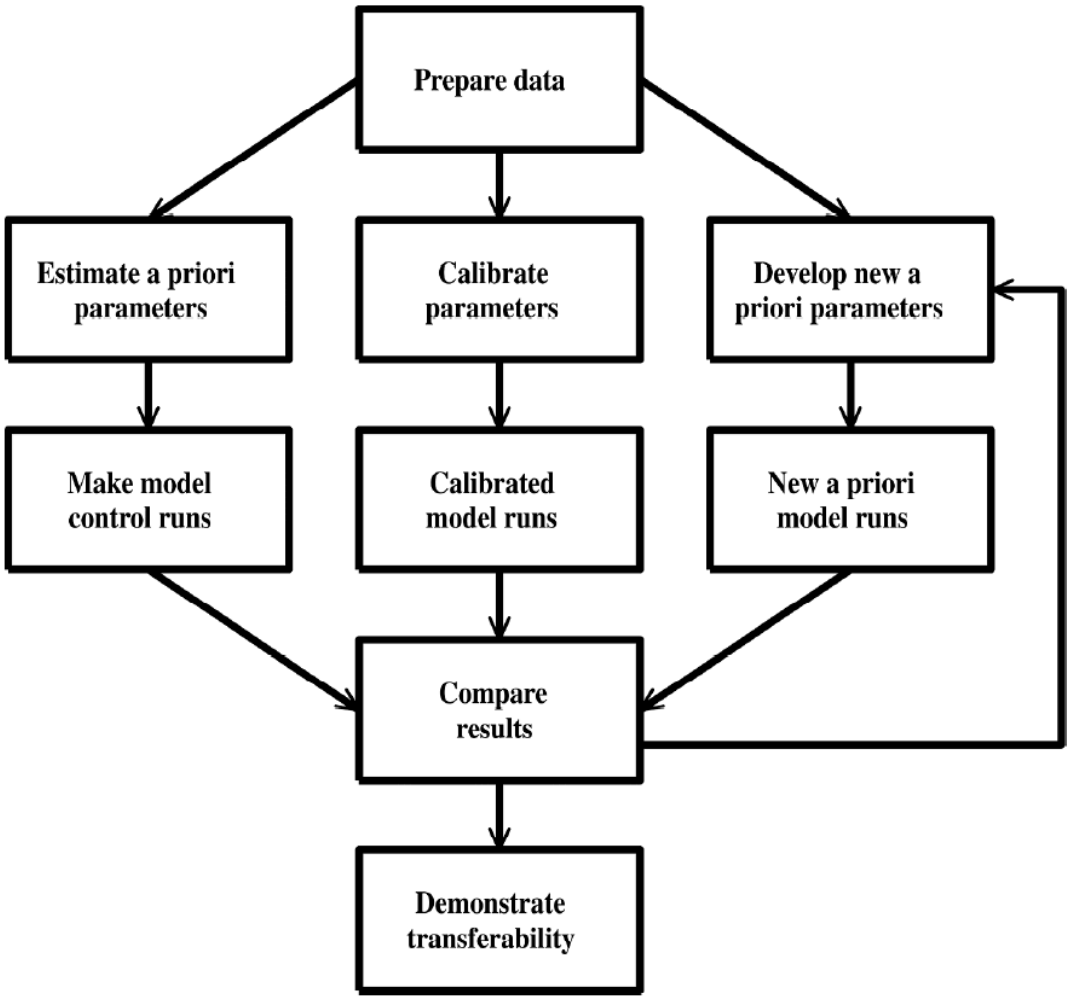

Figure 1. MOPEX implementation strategy.