Hydrology and Earth System Sciences Discussions

The Hydrologic Ensemble Prediction EXperiment (HEPEX)

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Abstract

Users of hydrologic predictions need reliable, quantitative forecast information, including estimates of uncertainty, for lead times ranging from less than an hour during flash flooding events to more than a year for long-term water management. To meet this
5 need, operational agencies are developing hydrological ensemble forecast techniques to account for sources of uncertainty such as future precipitation, initial hydrological conditions, and hydrological model limitations including uncertain model parameters. Research advances in areas such as hydrologic modeling, data assimilation, ensemble prediction, and forecast verification need to be incorporated into operational forecasting
10 systems to assure that the state-of-the-art products are reaching the forecast user community. The Hydrologic Ensemble Prediction EXperiment (HEPEX) has been formed to develop and demonstrate new hydrologic forecasting technologies, and to facilitate the implementation of beneficial technologies into the operational environment.

1 Objective

15 Development of reliable, skillful hydrologic ensemble forecast procedures is a major undertaking that requires global and multidisciplinary collaborations. The Hydrologic Ensemble Prediction EXperiment (HEPEX) (http://hydis8.eng.uci.edu/hepex/) is an international effort that brings together hydrological and meteorological communities to develop advanced probabilistic hydrologic forecast techniques that use emerging
20 weather and climate ensemble forecasts, such as those being developed by GEWEX (http://www.gewex.org/). The HEPEX mission is to demonstrate how to produce reliable hydrological ensemble predictions that can be used with confidence by emergency management and water resources sectors to make decisions that have important consequences for the economy, environment, public health and safety.

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2   Affiliations and participation

HEPEX is a global project affiliated with GEWEX to help GEWEX meet its water resource applications objectives. Also, it is an important GEWEX contribution to the overarching WCRP Coordinated Observation and Prediction of the Earth System (COPES) initiative (http://copes.ipsl.jussieu.fr/). HEPEX expects that the IAHS Predictions for Ungaged Basins (PUB) initiative (http://cee.uiuc.edu/research/pub/) will contribute both new science and data sets, and will participate in some of the test bed projects. Ensemble atmospheric forecasts are expected to be available for HEPEX applications from a number of models participating in the World Weather Research Project's THORPEX Interactive Grand Global Ensemble Experiment (TIGGE) (WMO, 2005). Brief descriptions of HEPEX were recently published in EOS (Franz et al., 2005) and in the GEWEX Newsletter (Schaake et al., 2005).

Participation in HEPEX is open to anyone wishing to contribute to its objectives. HEPEX activities will include test bed projects, development of supporting data sets, development of components of a Community Hydrologic Prediction System (CHPS), and sponsorship of workshops and special sessions at scientific meetings.

HEPEX invites potential forecast users to participate in HEPEX activities and the "Users Forum". The "Users Forum" helps oversee activities to assure user needs are being addressed. Users have been active participants in workshops and are involved in various HEPEX projects.

The first international HEPEX workshop was held 8–10 March 2004, hosted by the European Center for Medium-Range Weather Forecasts (ECMWF). This workshop initiated HEPEX and established its science agenda. The second workshop was held 19–21 July 2005 at the National Center for Atmospheric Research (NCAR) and initiated several test bed projects. Reports on these workshops are available on the HEPEX web site (http://hydis8.eng.uci.edu/hepex/).

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3   Science questions

The key science issue for HEPEX is reliable quantification of hydrologic forecast uncertainty. HEPEX plans to address the following key questions:

– What are the adaptations required for meteorological ensemble systems to be coupled with hydrological ensemble systems?

– How should the existing hydrological prediction systems be modified to account for all sources of uncertainty within a forecast?

– What is the best way for the user community to take advantage of ensemble forecasts?

4   Hydrologic Ensemble Prediction Systems

Two key goals of HEPEX are to develop and test the main components of a hydrologic prediction system (Fig. 1) and to combine these components to form the Community Hydrologic Prediction System. The purpose of CHPS is to greatly accelerate the infusion of new hydrologic science into hydrologic forecast operations. To accomplish this, CHPS is expected to be designed using an open system architecture that can easily accommodate the addition of new models and procedures into any one of the forecast system components. CHPS is expected to be both a testing ground for new forecasting technology and a pathway for integration of that technology into operations.

5   Test bed projects

A HEPEX Test Bed is a setting for HEPEX-community experiments. A test bed could be a single basin (and its subbasins), a region containing multiple basins, or possibly a global collection of basins that facilitate experiments addressing questions over a range

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of scales and climates. Regardless of geographical domain, test beds focus on one or more clearly defined HEPEX science questions; have the potential to develop data resources needed to address the questions of the HEPEX community experiments; and are expected to include active user participation. In addition, the test bed projects are needed to provide a framework for development of CHPS and to meet the HEPEX demonstration goal. Proposals for eight test bed projects were presented at the second HEPEX workshop. The proposed test beds are outlined in Table 1; and their global locations are illustrated in Fig. 2.

6 Application of weather and climate forecasts

One of the main links between GEWEX and HEPEX is that HEPEX hopes to demonstrate how to use improved climate forecast products that GEWEX will help to produce. This includes developing a seamless approach to the application of weather and climate forecasts through collaboration with the THORPEX Interactive Grand Global Ensemble project (TIGGE). TIGGE is "a project designed to develop, demonstrate and evaluate a multi-model, multi-analysis and multi-national ensemble prediction system" for short- to medium-range weather prediction (WMO, 2005). TIGGE is expected to provide an ensemble of two-week meteorological forecast inputs that can be used for hydrologic ensemble prediction experimentation by HEPEX.

Biases in weather and climate forecasts must be removed and the forecasts must be downscaled for hydrologic application. This requires an archive of forecasts and corresponding observations that can be used to estimate parameters of the hydrologic ensemble preprocessor. An important initial global source of meteorological ensemble forecasts is the archive of ensemble forecasts from the fixed version of the NWS Global Forecast System (GFS) for the period 1979 to the present (http://www.cdc.noaa. gov/people/jeffrey.s.whitaker/refcst/). Current ensemble forecasts from this system are available daily. A measure of the potential importance of the ensemble precipitation forecasts is the correlation between the ensemble mean and the corresponding obser-

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vation. The high correlation for 7- and 14-day total precipitation for most of the U.S., and the eastern/mid-western US and the mountain west in particular, demonstrates their potential for improving hydrological predictions (see Fig. 3).

7 Hydrologic uncertainty and data assimilation

There are many sources of hydrologic uncertainty; one of the most important is the uncertainty in initial conditions. Basin initial conditions are often difficult to identify for various reasons including a lack of reliable observations or the inability to directly relate model states to field observations. Therefore, for hydrologic ensemble prediction, an ensemble of initial conditions may be needed to effectively assess the impact on predictions. Most current data assimilation techniques aim to produce an optimal estimate in initial conditions and an estimate of uncertainty – but not ensemble members. Enhanced techniques that produce an ensemble of initial conditions and are also appropriate for operational forecasting are needed.

Other sources of uncertainty derive from model limitations, including model structure and corresponding estimates of parameter values. Representing this has been an important topic for the PUB initiative and for the international MOPEX project (http://www.seas.ucla.edu/~thogue/MOPEX/).

8 Operational application

The final acid tests for HEPEX will be whether the resulting prediction system(s) can be used in an operational forecast environment and the subsequent forecast products are beneficial to users and decision makers. It is highly unlikely that totally automated hydrologic ensemble prediction systems that ingest observations and weather and climate forecasts can be created to produce consistently reliable hydrologic ensemble forecasts without human forecaster involvement. Therefore the appropriate roles for

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human involvement must be found and demonstrated in an operational environment as well. Feedback from the user community will serve as the final verdict regarding the success of HEPEX, as the HEPEX goal emphasizes providing benefits to "emergency management and water resources sectors".

5 References

Franz, K., Ajami, N., Schaake, J., and Buizza, R.: Hydrologic Ensemble Prediction Experiment Focuses on Reliable Forecasts, Eos, 86(25), 239, 21 June 2005.

Schaake, J., Franz, K., Bradley, A., and Buizza, R.: Hydrologic Ensemble Prediction Experiment, GEPEX Newsletter, 15(4), 10, November, 2005.

10 WMO: First Workshop on the THORPEX Interactive Grand Global Ensemble (TIGGE), Final Report, WMO/TD-No. 1273, WWRP/THORPEX No.5, 1995.

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Table 1. Test Bed Projects.

Project	Objectives	Contact
Great Lakes, Canada/US	Demonstrate the importance of relatively detailed atmospheric and hydrologic modeling for medium-range atmospheric and hydrologic forecasting on large basins.	V. Fortin vincent.fortin@ec.gc.ca
Bangladesh	Provide operational real-time forecasts of river discharge into Bangladesh at daily, weekly, monthly, and seasonal time-scales.	Tom Hopson Thomas.Hopson@Colorado.EDU
Santa Fe Basin, Brazil	1. Explore the use of ensembles produced by the CPTEC model of global climate. 2. Explore the use of forecasts produced by RAMS for lead-times extending up to a month and longer. 3. Explore the use of short-term rainfall forecasts from the operational ETA model of CPTEC.	C. Tucci tucci@iph.ufrgs.br
Po Basin, Italy	1. Test simplistic routines for bias removal in an area such as Northern Italy that is dominated by important orography (Alps). 2. Test methods for flood forecasting based on threshold exceedances.	J. Thielen jutta.thielen@jrc.it
Western Basins, U.S./B.C., Canada	Develop hydrologic ensemble forecasting techniques that are particular to the orographically complex, snowmelt-driven basins of the Western US and British Columbia. Focus on monthly to seasonal lead times.	F. Weber Frank.Weber@bchydro.bc.ca A. Wood aww@hydro.washington.edu K. Werner Kevin.Werner@noaa.gov

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Table 1. Continued

| Project	Objectives	Contact
Southeast Basins, U.S.	Address the following HEPEX science questions: 1. How do we generate skillful and reliable meteorological forcing for seasonal hydrologic forecasting? 2. How do we generate the hydrologic ensembles that reflect the total uncertainties? 3. How can climate information, such as climate model forecasts or teleconnections, be used reliably in seasonal hydrologic forecasting? 4. How do we validate hydrologic ensembles for extreme events?	Eric Wood efwood@princeton.edu
Statistical Downscaling	1. Identify the space-time scales for which forecast skill is present for different variables and develop methods to extract and combine information at different space-time scales 2. Identify the GFS output variables that can be used to provide sub-grid information that can be used in a statistical model to replicate precipitation processes. 3. Identify the sample size required to reliably forecast precipitation, temperature, and streamflow, for different thresholds.	M. Clark clark@vorticity.colorado.edu J. Schaake john.schaake@noaa.gov
Hydrologic Uncertainty	Hydrologic uncertainty can be described in terms of uncertainties in model inputs, model parameters, and model structure; leading to uncertainties in model states and fluxes. What are the advantages and limitations of different methods for characterizing and reducing this uncertainty in hydrologic model simulations?	M. Clark clark@vorticity.colorado.edu J. Vrugt vrugt@lanl.gov
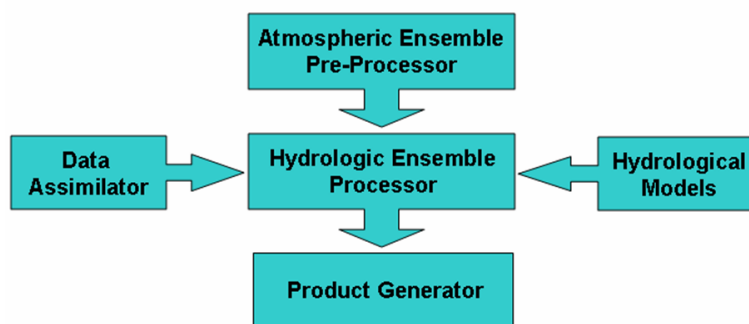
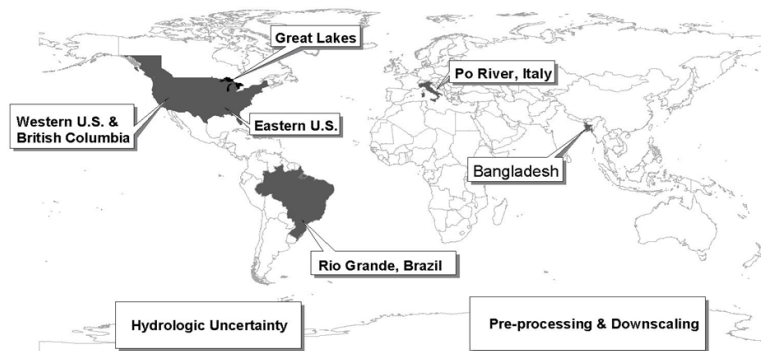**Fig. 1.** Components of a hydrologic prediction system.

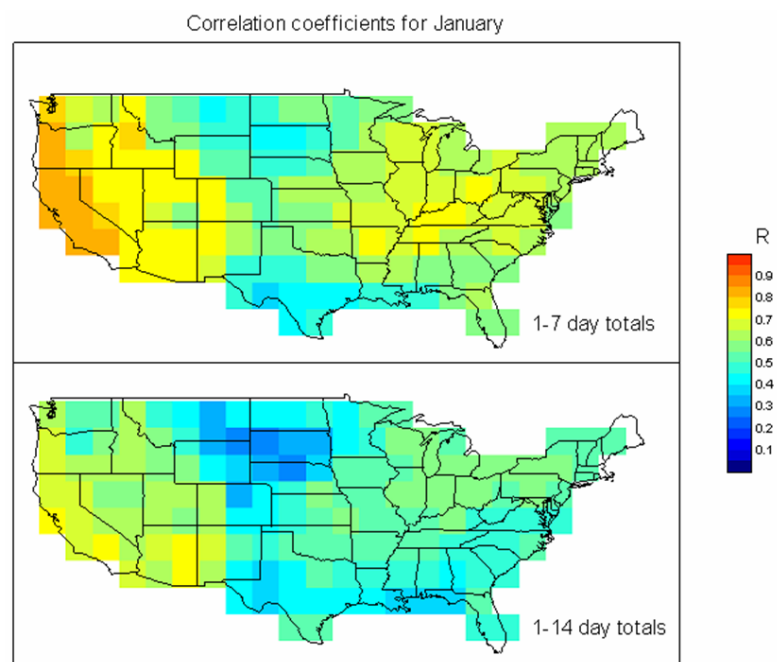**Fig. 2.** Global Locations of HEPEX Test-Bed Projects.

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Fig. 3. Correlation coefficients between observed and forecasted precipitation across the U.S. for January.

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