International Workshop on Hydrometeorological and Hydrologic Ensemble Prediction

19-22 July 2005

NCAR Foothills Laboratory
Boulder, Colorado, USA

Workshop Summary Report

Sponsored by:

HEPEX
Hydrologic Ensemble Prediction EXperiment

Co-Conveners:

Tom Hamill
NOAA-CIRES Climate Diagnostics Center

Martyn Clark
University of Colorado

John Schaake
NOAA/NWS Office of Hydrology

Roberto Buizza
European Centre for Medium Range Weather Forecasts

Hydrologic Ensemble Prediction Experiment (HEPEX)

What is HEPEX?

The Hydrologic Ensemble Prediction Experiment (HEPEX) is an international effort to advance technologies for hydrologic forecasting. It goal is:

To bring the international hydrological and meteorological communities together to demonstrate how to produce and utilize reliable hydrological ensemble forecasts to make decisions for the benefit of public health and safety, the economy and the environment.

The HEPEX project was launched in March 2004 at the International Hydrological Ensemble Prediction Experiment Workshop, held at the European Centre for Medium-Range Weather Forecasts (ECMWF) in Reading, UK. Since that workshop, HEPEX has sponsored sessions on ensemble prediction at various scientific meetings, and a 2nd HEPEX workshop was recently held in July 2005 at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA.

How will the HEPEX goal be achieved?

HEPEX will address critical science and user application problems in ensemble hydrologic prediction through a series of coordinated Test Bed demonstration projects. The test beds are designed to address key questions and challenges in ensemble prediction faced at specific watersheds or regions. HEPEX also facilitates interactions among test beds on cross-cutting topic areas as such:

- Downscaling information from numerical weather prediction models
- Data assimilation and hydrologic model initialization
- Characterizing uncertainties in hydrologic predictions

Who is involved in HEPEX?

The people involved in HEPEX are researchers, forecastors, and forecast users from operational forecasting agencies, academic and government research institutions, water management agencies, and private organizations. Individual HEPEX Test Beds are organized through the efforts of sponsoring institutions, groups, and agencies. Anyone interested in participating in HEPEX or one of its test bed projects is encouraged to join the effort.

What's next for HEPEX?

The first HEPEX Test Beds have been identified and experimental activities are now being planned. The next steps are to build the HEPEX community through the research opportunities facilitated by the test beds, seek support from funding agenices and associations with related research programs, and begin carrying out collaborative research at the test beds. Over the next two years, we anticipate making significant strides in implementing the HEPEX science agenda, and will report on our accomplishments at the 3rd HEPEX Workshop in Ispra, Italy, in 2006.

Hydrological Ensemble Prediction Experiment (HEPEX)

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Summary Report

1. INTRODUCTION

The *International Workshop on Hydrometeorological and Hydrologic Ensemble Prediction*, sponsored by the Hydrological Ensemble Prediction Experiment (HEPEX), was held at the NCAR Foothills Laboratory in July 2005. This 2nd HEPEX Workshop convened to discuss the coupling of ensemble weather forecast data into hydrologic prediction systems, the latest results in the development of ensemble weather prediction systems, the development of hydrologic prediction systems, and the integration of the two.

The discipline of coupling weather and hydrologic systems has advanced rapidly in the past few years. Yet to achieve the HEPEX goal to produce and utilize reliable "engineering quality" hydrologic predictions will require the scientific community to develop creative solutions to a host of difficult prediction problems. Topics that need to be addressed by HEPEX include techniques for using weather and climate information in hydrologic prediction systems, new methods in hydrologic prediction, data assimilation issues in hydrology and hydrometeorology, verification and correction of ensemble weather and hydrologic forecasts, and better quantification of uncertainty in hydrological prediction. As pathway for addressing these topics, HEPEX plans to set up demonstration test bed projects, and develop data sets, for the intercomparison of coupled systems for weather (or climate) and hydrologic forecasting, and their assessment for meeting end users' needs for information to make decisions for the benefit of public health and safety, the economy and the environment.

The workshop consisted of oral and poster presentations, plenary session discussions, working group breakout sessions, and a planning meeting. Oral session presentations were made on Tuesday through Thursday on the topics of (1) weather and climate forecasting for hydrologic predictions, (2) data assimilation and modeling techniques for hydrometeorological prediction, and (3) meteorological and hydrological applications. Follow-up plenary sessions allowed extend discussions on each session topic. Poster presentations were also available for viewing throughout the week. The agenda for the workshop is shown in Section 7; links to presentations are available through the HEPEX web site at:

http://hydis8.eng.uci.edu/hepex/

Afternoon working group breakout sessions were held on Tuesday and Wednesday. The Test Bed Working Group discussed how to organize test beds to answer the primary HEPEX science questions. The Datasets & Models Working Group discussed what datasets and models are required to answer the primary HEPEX science questions. The Users Working Group discussed what can be done to foster and nurture collaboration with users. Presentations and discussion of workgroup group findings and recommendations were made at two plenary sessions. The final reports from the three working groups appear in Sections 2 through 4 of this report.

A HEPEX Steering Group planning meeting was held on Friday. All participants of the workshop were invited to attend. Topics discussed at the meeting included the follow-up reports and publications from the 2nd HEPEX Workshop, the organizational structure for HEPEX, and timing and location of the next HEPEX meeting. The HEPEX goal statement was also reviewed and revised. A summary of the planning meeting appears in Section 5.

As part of the plenary session discussions on Thursday, a preliminary set of test bed demonstration projects was identified. A brief description of each of these test beds appears in Section 6.

2. TEST BED WORKING GROUP REPORT

The concept of HEPEX Test Beds demonstration projects was proposed at the 1st HEPEX Workshop as a way to focus research on techniques for ensemble prediction techniques and their application in decision making. The Test Bed Working Group met to discuss and refine the test bed concept for HEPEX. Questions outlined during the plenary session to guide the discussion are shown in Table 2.1.

Overall Question: How can we organize test beds to answer the primary HEPEX science questions? ▪ What regional test beds are currently out there? ▪ How are regional test beds organized? ▪ What are the criteria for an official HEPEX project? What is the process to legitimize HEPEX projects? ▪ How can we learn from the different regional test beds and foster collaboration among the different regional efforts (e.g., reporting requirements)? ▪ How can we organize community projects for specific HEPEX science questions (data assimilation; downscaling, etc.)? ▪ What are the data requirements for HEPEX Test Beds? ▪ How can HEPEX interact with other international projects (e.g. TIGGE)?

Table 2.1: Discussion Questions for the Test Bed Working Group

2.1 What is a HEPEX Test Bed?

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 a collection of individual basins that facilitate experiments addressing questions over a range of scales and climates. Regardless of its geographical domain, a test beds would address one or more clearly defined HEPEX science questions, and have the data resources (either existing or potential) needed for community experiments to address the questions.

Recommendation: The criteria for an official HEPEX Test Bed are: (1) a location, or set of locations, that can test specific HEPEX science objectives; (2) sufficient data resources that are freely available to the research community; and (3) a sponsoring lead group or agency that will help to facilitate experiments. Existing forecasting capabilities and user communities are strongly desired, but are not required at every test bed. The HEPEX Steering Committee will designate official HEPEX Test Beds upon review.

2.2 How to organize HEPEX Test Beds?

With no direct source of funding for activities proposed by HEPEX, leveraging ongoing activities to facilitate collaborative research and community building is a primary mechanism to achieve HEPEX goals. Therefore, the establishment of test beds for community research activities will require organizations to sponsor the designation of a location, or set of locations, as a HEPEX Test Bed. Individuals at the organization must provide leadership in helping to formulate the HEPEX science experiments that are best-suited site, and offer supporting data sets to the community. Furthermore, sponsoring organizations are essential for each test bed to provide local knowledge on the climate and landscape, and connections with existing operational forecasting capabilities and user communities.

Recommendation: Sponsors for a proposed HEPEX Test Bed should submit a 2 or 3-page prospectus to the HEPEX Steering Committee for consideration. The HEPEX Steering Committee will review the initial portfolio of submitted Test Bed proposals for designation by February 2006 [6 months].

Each prospectus would contain the following elements:

1. A definition and brief description of the test bed.
2. Proposed HEPEX science questions that the test bed would be best-suited for addressing.
3. A description of the data resources, including those existing, and those needed to address proposed science questions. The sponsor should also specifically explain what data resources it could provide to the HEPEX community.
4. An explanation of what the sponsor would like to achieve through experimentation at the Test Bed, and what it would like others in the community to join in to do.
5. A description of existing operational forecasting capabilities and forecast users in the test bed, as well as other potential users of ensemble forecasts.

2.3 Data to Facilitate Community Efforts at HEPEX Test Beds

The test-bed concept provides a common framework for how we go about doing experiments. Likewise, a common framework for describing and exchanging data within HEPEX Test Beds is a priority. In most cases, data access is not a problem at test bed sites. However, processing the data into a suitable format is both expensive and time consuming. HEPEX guidance to standardize data exchange formats for HEPEX Test Basin would be critical to facilitating community research. This work does not need to start from scratch; acceptable guidelines exist from other experiments and activities that could be adopted for HEPEX Test Bed. However, rather than enforcing a single data format for a certain variable, narrowing the suite of data formats, and/or recommending preferred data formats, is needed.

Recommendation: The HEPEX Data Management Working Group needs to review existing data formats and provide data format guidelines by 6 months.

2.4 Funding to Facilitate Community Efforts at HEPEX Test Beds

With no direct funding available for test beds, HEPEX must adapt research to the existing funding situation. Indeed, the success of HEPEX Test Beds will rely more on the community's willingness to make things happen, than on funding. Still, some funding to facilitate meetings would be useful. Also, to facilitate HEPEX activities at academic and research institutions, collaborations growing out of test bed research opportunities must lead to funded proposals.

Recommendation: HEPEX Test Bed sponsoring groups and interested agencies are encouraged to write letters of support, and join as collaborators or co-PIs, in the proposals of research institutions to funding agencies.

3. DATASETS AND MODELS WORKING GROUP REPORT

The success of HEPEX Test Bed demonstration projects will depend on availability of experimental datasets and modeling capabilities that facilitate collaborative research by the HEPEX community. The Datasets and Models Working Group met to discuss the data and modeling requirements to implement the test bed concept. Questions outlined during the plenary session to guide the discussion are shown in Table 3.1.

Overall Question: What datasets and models are required to answer the primary HEPEX science questions?

- Discuss necessary atmospheric forecast archives and hydrometeorological datasets (precipitation, temperature, snow, streamflow, basin characteristics)
- Can datasets be better organized to decrease processing time for individual investigators?
- How can we provide some generic modelling architecture to decrease analysis time for individual investigators?
- How can datasets be organized/distributed for regional test beds?
- Data formats, ...
- How can HEPEX interact with other international projects (e.g. TIGGE)?

Table 3.1: Discussion Questions for the Datasets and Models Working Group

3.1 Test Bed Selection and Data/Modeling Needs

The Datasets and Models Working Group quickly recognized that the selection of test beds and specification of modeling/data requirements are strongly dependent. Availability of a long-term archive of hydrologically relevant data determines prime test bed sites while lack of data for a potential test bed determines needs. The Test Bed Working Group should define data needs after identifying potential test sites while the Datasets and Models Working Group should propose potential experiments for test beds that will depend on available data. It is critical that user needs also be considered in the selection of test beds and proposed experiments.

Recommendation: Liaisons between working groups are needed to coordinate HEPEX efforts towards a sensible integration of test beds, data needs, experiments and user requirements.

Test beds should be selected by their characteristics to ensure representative sampling. Important characteristics include climatology (tropical, semiarid, temperate), terrain (snowpack-driven mountains vs. precipitation-driven flat, etc.), hydrologic issues (small basins prone to flash flooding vs. large river basin) and user perspective (regulated vs. unregulated). The question is how many to choose since data needs would scale quasi-linearly with the number of basins. HEPEX should resist the temptation to emphasize extreme events that would likely lead to unrepresentative sampling in order to minimize data requirements. To be a successful program HEPEX must be thorough, which means data demands will be large in terms of volume, bandwidth, and storage.

3.2 Data Requirements for Hydrologic Models

Data requirements for land surface models (LSM) include time-varying initial conditions such as vegetation, soil and snow/ice characteristics. Forcing data is primarily precipitation (amount and type), but it also includes other meteorological relevant fields (e.g. temperature, moisture, wind, etc.). Relevant hydrologic scales for forcing data are as fine as O(1 km) and O(1 h) for flash flooding areas, and as big as a large basin itself and as long as several days for seasonal forecasts. The primary verification data are streamflow, but for regulated basins, water management statistics and usage must also be obtained. HEPEX desires more than 30 years of the above data in order to sample interannual variability and capture several extreme or high-impact events.

Recommendations:

1. Data sets of 30 years (or longer) duration are desirable for HEPEX test beds.
2. Time-varying initial conditions are need for vegetation, soil and ice/snow. These data suggest the importance of obtain a long archive of relevant satellite observations.
3. Streamflow data are required at requisite temporal scales. Water management and usage statistics for regulated basins are needed, which requires working closely with municipal regulatory agencies and the private sector.

Meteorological forcing data are needed at appropriate hydrological scales. The primary forcing data are precipitation amount and type. Data from gauge, radar estimates and satellite retrievals are of value, as are “blended” analyses. Other atmospheric data include those needed for runoff models of varying complexity (e.g. temperature, wind speed, etc.).

3.3 Hydrologic Forecast Models

A suite of hydrologic models should be made available for HEPEX researchers to allow testing of hypotheses and performance. The suite should range from full surface energy balance models, to simple conceptual runoff models, to statistical calibrations.

Recommendation: HEPEX participants should allow fellow HEPEX researchers access to their hydrologic runoff models. It is desirable that donors provide basic written documentation for their models in terms of driver scripts to run the model, expected input data and produced output, data formats, and supported platforms.

3.4 Atmospheric Model Information for HEPEX

HEPEX, by design, requires ensemble forcing analyses and weather forecasts. The Datasets and Models Working Group endorses in principle the proposal for a THORPEX/HEPEX Hydrological Applications Project (THEPS). Operational weather centers produce global ensemble forecasts at various resolutions and forecast projections, several times per day. HEPEX should encourage operational weather forecast centers to allow free, unencumbered exchange of their ensemble output for research purposes and to archive data at full horizontal resolution for the relatively small areas that would cover test beds. Temporal sampling should not be longer than 3-6 hours in order to resolve the diurnal cycle and more frequent for certain forcing fields (e.g. precipitation) early in the forecast. Horizontal sampling ideally should be on a model's native grid, or transformed to grids consistent with model's smallest resolvable scales. We note that data volume for the surface fields that are relevant to hydrological runoff models is small. On the other hand, data from the outer domain that are necessary to drive a limited area model (LAM) is much larger, at least at the initial time. Full ensemble fields at the finest spatial resolution are needed for primary model variables (temperature, winds, water vapor) at $\tau=0$, but they are only needed along the lateral boundaries of the LAM at subsequent forecast times (e.g. hourly updates).

A cursory survey of forecast centers reveals many potential donors for global forecast fields to ranges of 10-15 days, including NOAA/NCEP, NOAA/CDC, ECMWF, UKMET, CMC, JMA and BOM. These agencies are participating in the THORPEX Interactive Grand Global Ensemble project (TIGGE); TIGGE data are being archive now and should become available in 2006. Some agencies run monthly and seasonal forecasts (e.g. NCEP, ECMWF, IRI), and such forecast data may be available through other programs (WCRP). LAM forecasts at finer resolution for short-range are issued by NCEP for the CONUS (e.g. Eta, NNM, RSM, RUC, SREF) and several European states. Long-term archives of ensemble reforecasts by frozen models, as pioneered by NOAA/CDC, are an invaluable asset for HEPEX calibration work and should be obtained whenever available.

Recommendations:

1. HEPEX should compose a document that describes the benefits to the operational centers in providing data to the HEPEX program.
2. Request that relevant operational and research centers provide their ensemble output at full horizontal resolution and requisite temporal intervals for test bed regions, and they allow free exchange of their datasets among HEPEX participants for research purposes.
3. Researchers interested in examining dynamical downscaling should formulate a proposal to the operational centers for obtaining initial and lateral boundary conditions that are required to drive cloud-permitting LAM's over test bed regions.

4. Encourage operational centers and research centers to produce reforecasts for simplified versions of their global models and LAM's.

3.5 Data Management

The logistics of data management for HEPEX must be considered and overcome prior to the beginning of the project. A central web site that contains a directory, a HEPEX Yellow Pages so to speak, of available data, data formats, models, analysis software, documentation, supported platforms would prove very useful to the community. There needs to be standards imposed on HEPEX in terms of documentation, flexible access to data, data formats and archiving sites.

Recommendation: HEPEX should immediately form a Data Management Committee to develop a plan for archiving, documentation, format standards, and free, open and flexible access to data, models and software.

4. USERS WORKING GROUP REPORT

Reliable ensemble hydrological forecasts have value if they help users make better decisions. User participation in HEPEX research is a fundamental component that defines the relevance of all HEPEX activities. The User Working Group met to discuss ways to promote collaborative activities with users to help guide HEPEX activities and test bed research. Questions outlined during the plenary session to guide the discussion are shown in Table 4.1.

Overall question: What can we do to foster and nurture collaboration with users? ▪ What are the main categories of users (e.g., hydrologic service providers [RFCs]; decision-makers [reservoir operators, municipalities]; private consulting companies)? ▪ What is the role of the different users in HEPEX? What is the role of the private sector, and how can HEPEX stimulate private sector activities? What is the role of hydrologic service providers and how can they participate in HEPEX activities? ▪ What are the major constraints that limit use of HEPEX science products? Based on this, how can users help define/refine the HEPEX science questions and HEPEX implementation issues? ▪ How can users provide input on the delivery of hydrologic forecast products (e.g., timing, format [individual ensembles; prob. exceedance])?

Table 4.1: Discussion Questions for the Users Working Group

4.1 What are the main categories of users?

The group went through the exercise of identifying the various groups and sectors that would or could benefit from reliable ensemble hydrologic predictions of streamflow. Table 4.2 shows the categories of users. The list is not necessarily exhaustive, but is a pretty good start. Other organizations are certainly possible.

It was noted that users may have a whole spectrum of requirements, even within individual sectors or categories. Some users may have very specific quantitative needs while others may need only qualitative information. It was also noted that we can and should expect to discover additional users and customers for HEPEX information over time.

4.2 What is the role of the different users in HEPEX?

Given the broad spectrum of users identified in Table 4.2, there are a whole host of appropriate roles. However, it was generally agreed that the greatest contribution could potentially come through the process of identifying requirements and assessing the ability of HEPEX related products to meet user needs. An effective feedback loop between users and the science community will facilitate the effective and efficient development of needed capability. This feedback loop will require a close working relationship between developers and selected users representing as many sectors as reasonable. Demonstrating value to user communities is essential from both a support and marketing perspective. In this context marketing is used to describe the process of making potential users aware of the benefits available through the use of HEPEX technologies.

Flood Management ▪ Reservoir and Flood Control	Science ▪ Weather/Climate Models ▪ Academic/Research	Commerce ▪ Power Generation ▪ Navigation ▪ Commodity Market ▪ Insurance
Emergency Management	Trainers/Educators	Water Supply ▪ Agriculture ▪ Municipal
Recreational	Forecasters	Data Collection Groups
Value Added Services ▪ Customization ▪ Decision Support ▪ Legal (water law, litigation)	Environmental ▪ Fisheries ▪ Water Quality	Other

Table 4.2: Groups and Sectors

Test beds should necessarily include a broad spectrum of users and include features that allow HEPEX to demonstrate value to specific sectors. In the plenary discussion, it was appropriately identified that at least one test bed should be identified from the User perspective.

Users will have a significant role in the education and training process. Education and training are required for all sectors in order to make full use of the potential information. Users will also have a role in facilitating the availability of HEPEX information and technology through maintaining open systems and sharing information.

4.3 What are the major constraints that limit use of HEPEX science products?

The HEPEX community is dominated by a combination of researchers and those involved in the forecast process. Representatives of the user communities are largely unrepresented. As such, HEPEX must work to effectively market its capabilities. Marketing is not an evil activity. It is the simple act of making potential users aware of the service and clearly demonstrating value in their terms and units. In many cases, the demonstrated value must be compelling enough to overcome entrenched cultural practices. A very significant effort will be required to do this effectively. User input and guidance should be integrated into the HEPEX process at all levels.

Hydrologic ensemble prediction is not a resolved science. While we are interested in demonstrating value to users, we have to realize and recognize that we don't have all the answers and cannot currently provide everything. Expectations should be realistic and we must avoid "over selling and under delivering."

Information technology infrastructure represents a very real physical constraint. Much of this can be avoided by agreeing to share information openly and in common formats. Issues associated with meeting security policies are not likely to be resolved and will need to be managed to the extent possible.

Available resources will likely be a constraint. It costs time and money to work with users to demonstrate and integrate new technology into existing decision support systems.

Training is a big issue. Most people have some awareness of risk, but are unfamiliar with how to use it to their advantage.

4.4 How can users provide input on the delivery of hydrologic forecast products?

The group reinforced the need for the HEPEX User Council. Further, it is important that users be closely associated with the research and development process. Continuous feedback is needed. It was noted that HEPEX cannot hope to engage all users, but should instead attempt to forge relationships with selected representative users who are interested in participating and contributing to the process.

It was also suggested that some sort of online interface be developed and supported. This interface might serve as a clearinghouse for information as well as a forum for the exchange of ideas, concepts, software, techniques, and the like.

4.5 Attributes of a User-Focused Testbed

It was suggested in the plenary section, that a User-Focused Test Bed may be appropriate. In many cases, test beds are chosen because they provide an environment where the science issues can be effectively resolved. The notion of a identifying a test bed based on user needs and addressing the required science issues, whatever they are, is intriguing.

In order to effectively address the needs of potential users, it is important to fully understand their business model. What information do they need and how is it used in their decision making process? This process is more likely to be successful if users are integrated into the HEPEX process. This necessarily means that HEPEX should engage representative users as apposed to all users.

An effective test bed would also provide meaningful verification and validation information in the context and units of the user's business. Users who actively advocate HEPEX technologies to their community will facilitate awareness, interest, and support. This is essential to the success of HEPEX.

User-focused Test Beds should be selected where a broad diversity of users exists, including some non-traditional ones. It was noted that the hydrologic forecasters who provide uncertainty information to their customers are users.

5. HEPEX STEERING COMMITTEE PLANNING MEETING

A planning meeting of the HEPEX Steering Committee, open to all the participants of the 2nd HEPEX workshop, was help on Friday. Discussion topics included the HEPEX goal, reports and publications from the 2nd HEPEX Workshop, the HEPEX Organizational Structure, and future meetings. The following sections summarize the discussions at the meeting.

5.1 HEPEX Goal

HEPEX goal as formulated at the 1st HEPEX Workshop in March 2004 is:

> *HEPEX aims to bring the international hydrological and meteorological communities together to demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence by the emergency management and water resources sectors to make decisions that have important consequences for the economy, for public health and safety.*

In an effort to make the statement more concise, the following revised goal was proposed:

> *HEPEX aims to bring the international hydrological and meteorological communities together to demonstrate how to produce and utilize reliable hydrological ensemble forecasts to make decisions for the benefit of public health and safety, the economy and the environment.*

5.2 Workshop Reports and Publications

Based on a discussion, the participants recommended several reports and publications:

2nd HEPEX Workshop Report

The participants recommended presenting the outcomes of the workshop in several forms. First, a workshop report, consisting of a summary of the discussions, working group breakout meetings, and the planning meeting, will be prepared. The report will also contain brief (1 or 2 page) descriptions of the proposed HEPEX Test Beds. Second, the HEPEX web site (http://hydis8.eng.uci.edu/hepex/) will be updated with links to the workshop report, and contain an agenda with links to all the presentations.

HEPEX Presentation for NRC Climate Research Committee

The NRC Climate Research Committee will hold a meeting on 3-4 October 2005 in Washington D.C. At the meeting, the World Climate Research

Programme (WRCP) will launch COPES (Coordinated Observation and Prediction of the Earth System). COPES is a new strategic framework for WRCP activities over the next decades, with the goal to "facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society".

HEPEX will seek to be involved in the upcoming meeting, and make a presentation on the HEPEX goals and strategic plan.

HEPEX Strategic Plan

The participants recommended that HEPEX prepare a strategic plan, describing its science objectives and implementation strategy. Audience for the HEPEX Strategic Plan would include both potential and current participants, participants of related weather and climate research programs, and agencies and institutions that fund research in the atmospheric and hydrologic sciences.

HEPEX Journal Article

A summary article, based on the HEPEX Strategic Plan, and suitable for journal publication, was recommended. The article would help to make the scientific community aware of the HEPEX science goals and implementation plans, and explain how potential participants can become involved.

The outline for the HEPEX Strategic Plan and journal article was discussed. The proposed format for these publications is:

1. HEPEX Goal
2. HEPEX Motivation
    i. Scientific issues
    ii. Users' applications:
        a. Water resources management
        b. Risk management
3. HEPEX Organization: structure, terms of reference for the Steering and Users' Committee
4. HEPEX Test Beds
5. HEPEX Plan and Deliverables
6. HEPEX Relation with other Programmes (WCRP, THORPEX, COPES, IAHS, ...)
7. Appendix: Test Beds detailed description

Based on the discussion, the following schedule and deadlines was proposed for workshop reports and publications:

Date	Description	Individuals
15 Aug 2005	1-2 Page Test Bed Descriptions	Test Bed Leaders
1 Sep 2005	Summary and Minutes of the 2nd Workshop	M. Clark T. Hamill A. Bradley
1 Oct 2005	Draft presentation for the NRC Climate Research Committee Meeting in October (Washington D.C.)	E. Wood A. Hall J. Schaake
Oct-Nov 2005	Finalize Strategic Plan	J. Schaake R. Buizza
Nov 2005	Write HEPEX article based on strategic plan for journal publication	T. Hamill (lead)

5.3 HEPEX Organizational Structure

The planning meeting participants considered two alternative organizational structures. Participants strongly favored the matrix organization shown in Figure 5.1. As opposed to a top-down structure, the advantage of the matrix organization is that it would promote both the local organizational flexibility needed at test bed sites and the intercommunication needed for successful international synthesis. The components of the structure reflect both the HEPEX science topic areas and their study within the Test Bed demonstration projects. The User Committee and the Science Steering Group would provide input and guidance to coordinate HEPEX activities.

The User Council will oversee and advise the Science Steering Group, the Topic Area Work Groups, and the Test Bed Projects on project priorities from the perspective of potential users of ensemble hydrologic predictions or prediction technologies. The group will be composed of representatives of organizations with a strong interest in using or applying HEPEX results. The User Council Chair will appoint members of the User Council who will serve for two year terms that may be renewed. Members of the User Council will elect the User Council Chair. At least two members of the User Council will also serve on the Science Steering Group.

The primary leadership of the HEPEX project activities is the responsibility of the Science Steering Group. The group will be composed of representatives of organizations affiliated with the project. It is expected that members of the steering group will also serve as chairs or co-chairs of the cross-cutting Topic Area Work Groups, and leaders of the HEPEX Test Bed projects. Participants recommended having two people serve as co-chairs for each Topic Area Work Group; a Test Beds group would be chaired by the sponsors of the test bed. The steering group will elect a chair and co-chair. Steering group members will serve for two year terms that may be renewed. Members of the steering group will be appointed by the Chair in consultation with the Co-Chair.

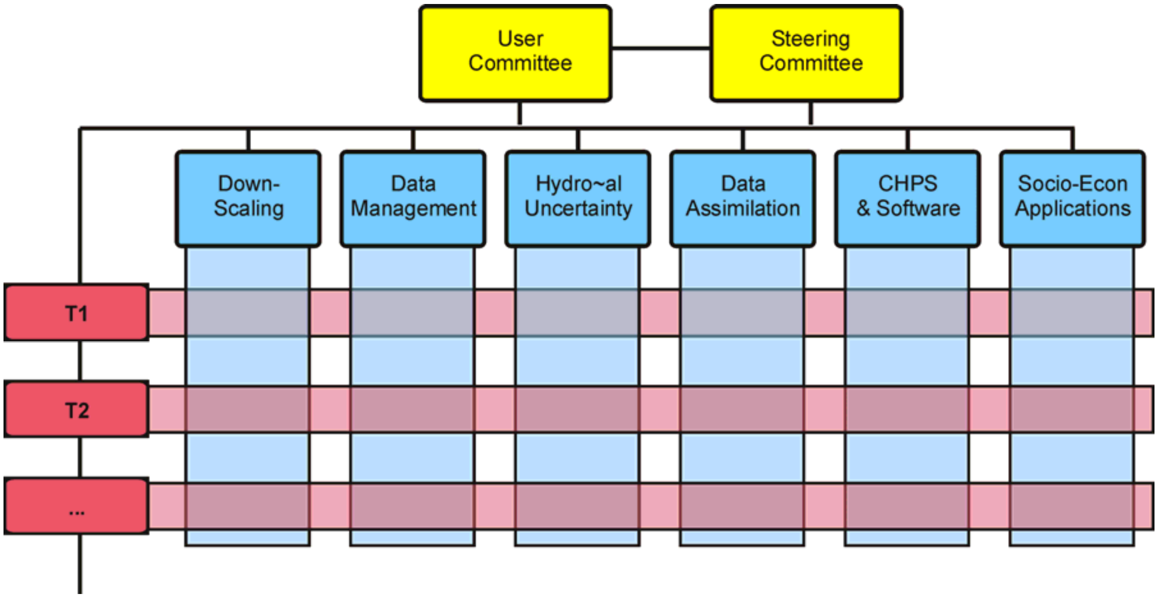

Figure 5.1: HEPEX Organizational Structure

Prior to the 2nd HEPEX Working, potential candidates for the HEPEX Users and Steering Committees were identified. The candidate members represent a mixture of areas of expertise, geographical regions, and institutional capabilities. Other criteria included a commitment and potential for deliverables. The membership of the committees (with additions made at the planning meeting) is shown below.

Appointments to the committees will be revisited and revised at the 3rd HEPEX Workshop in 2007.

Users Committee

Co-Chairs:

- Chuck Howard
- Rob Hartman

Members:

- Kevin Berghoff
- David Brandon
- Noel Evora
- Mukuteswara Gopalakrishnan
- Thomas Hopson
- Luc Perreault
- Ann McManamon
- Tomas Pagano
- Andrea Ray
- Frank Weber
- Kevin Werner

Science Steering Committee

HEPEX Co-Chairs:

- John Schaake (NOAA, US)
- Roberto Buizza (ECMWF, EU)

Members:

- Newsha Ajami (UC-Irvine, US)
- Raymond Arritt (Iowa State Univ., US)
- Allen Bradley (Univ. Iowa, US)
- Martyn Clark (Univ. Colorado, US)
- Vincent Fortin (MSC, Canada)
- Kristie Franz (UC-Irvine, US)
- Allan Hall (IAHS/GEWEX, Australia)
- Tom Hamill (NOAA/CDC, US)
- Rob Hartmann (NOAA/NWS, US)
- Tom Hopson (Univ. Colorado, US)
- Chuck Howard (Canada)
- Steve Mullen (Univ AZ, US)
- Erik Spokkereef (RIZA, Germany)
- Jutta Thielen (JRC, EU)
- Stefano Tibaldi (ARPA-SMR, Italy)
- Ezio Todini (Univ. Bologna, Italy)
- David Toll (NASA, US)
- Zoltan Toth (NCEP, US)
- Carlos Tucci (Univ. Rio Grande, Brazil)
- Eric Wood (Princeton Univ, US)
- WMO Representative

5.4 Future Meetings

Times and locations for the 3rd HEPEX Workshop were discussed. The proposed time frame for the next meeting is 2nd or 3rd quarter of 2007. The Joint Research Centre (JRC) of the European Commission in Ispra, Italy, has kindly offered to host it.

6. PROPOSED TEST BEDS

At the Thursday Afternoon Plenary Session, the participants identified a set of proposed HEPEX Test Beds:

- T1: Great Lakes and St. Lawrence River
- T2: Southeast United States
- T3: Western US and British Columbian
- T4: Rio Grande Basin Brazil
- T5: Model Uncertainty
- T6: Po Catchment in Italy
- T7: Brahmaputra and Ganges Basins
- T8: NAME Region
- T9: Statistical Downscaling

Other potential test beds were also discussed. To improve the geographical coverage of test beds, regions in Africa, perhaps as part of the African Monsoon Multidisciplinary Analyses (AMMA), and in China, were suggested. Also, to address issues raised by the Users' Working Group, a test bed to examine the value of hydrological forecasts may be needed.

Brief details of each proposed test bed are summarized in the remainder of this section.

Test Bed 1: Great Lakes and St-Lawrence River

Test Bed Leaders:

- Vincent Fortin, Meteorological Service of Canada, Canada
- Alain Pietroniro, National Water Research Institute, Canada

Test Bed Description:

The Great Lakes basin, located at the Canada-US Border (cf. Fig. 1), contains approximately 20% of the world fresh water supply. The watershed area is approximately 1 million km^2 and close to 40 million people live on this watershed, including roughly one third of the population of Canada. Water empties from the Great Lakes into the St. Lawrence River and passes through the Moses-Saunders dam at the outlet of Lake Ontario.

Decisions on Lake Ontario outflows are typically taken on a weekly basis and are based on lake levels, forecasted inflows to the lake and forecasted outflows from the Ottawa River basin for the following weeks, and thus may benefit from better ensemble streamflow forecasts both of Lake Ontario inflows and Ottawa River flow for the first 15 days. At this time scale, ensemble streamflow forecasts should benefit from an accurate analysis of initial conditions (snow and soil moisture) as well as ensemble weather forecasts.

Fig.1 The Great Lakes basin[1]

Key Scientific Questions:

While the Great Lakes basin is fairly large, individual lakes and in particular Lake Ontario, are fed by a number of much smaller watersheds. It is known that for some of these watersheds, for example the Raquette river which takes its source in the Adirondack mountains, basin average snow water equivalent is better estimated from a

[1] Taken from the web site of the Council of Great Lakes Governors, http://www.cglg.org/projects/water/docs/6-30-05/GLBasinMap.pdf

high resolution analysis.[2] It is also known that the Great Lakes influence both winter-time and summer-time weather at the regional scale.[3,4] Given the importance of resolving the terrain and the lakes for realistic hydrometeorological modelling of the Great Lakes, this test bed can be used to test the influence of increased resolution both for the land-surface scheme and for the atmospheric model on the accuracy and reliability of ensemble streamflow forecasts and ensemble weather forecasts.

Key Objectives of the Research Project:

The Great Lakes and St-Lawrence testbed can serve to demonstrate the importance of relatively detailed atmospheric and hydrologic modeling for medium-range atmospheric and hydrologic forecasting on large basins. The Great Lakes testbed can also be used to evaluate the added value of using the new North American Ensemble Forecasting System (NAEFS), compared to only using ensemble forecasts from the individual centers (CMC and NCEP), but also compared to the GFS reforecasts. Finally, as there is considerable hydroelectric power production on the basin, and as some of the hydropower companies such as Hydro-Québec can readily use better ensemble streamflow forecasts to improve their operations, the testbed can be used to evaluate the added economic value of using ensemble weather predictions instead of climatology for lead times of up to two weeks. The HEPEX scientific community will be asked to propose and test different strategies for downscaling the atmospheric forecasts for specific events, and for hydrological modelling. The user community will be asked to help evaluate the economic value of the forecasts.

Data Resources:

The Great Lakes Environmental Research Laboratory[5] maintains a comprehensive database of hydrologic, meteorologic, climatic, nivometric and physiographic data. Monthly hydroclimatic time series dating back more than a century are available. More than 180 hydrometric stations on unregulated basins are currently active on the Canadian side of the border. Daily hydrometric and meteorologic observations are available freely through the web, 6-hourly data is available for synoptic weather stations. A 15-km analysis of precipitation combining the regional GEM model first guess with synoptic observations is available in realtime for the whole basin, as well as a 10-km radar mosaic.

Land cover information is available for the US through the Great Lakes Assessment Project of the U.S. forest service[6] or through the NOAA Coastal Services Center[7], and for Canada through the Ontario land cover database. Soil information is available from the

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[2] Lefaivre, D.; Pellerin, P.; Ritchie, H.; Turcotte, R.; Fortin, V.; Pietroniro, A.; and Lamontagne, M. 2004. Water level forecasting in the St. Lawrence River between Lake St. Louis and Quebec City: Ongoing operation and future outlook. 11th Annual International Conference on the St. Lawrence River Ecosystem, Cornwall, Ontario. May 18-19th, 2004.

[3] Bosart, L. and T.J. Galarneau Jr. 2005. The Influence of the Great Lakes on warm season weather systems during BAMEX, 6th AMS Coastal Meteorology Conference, San Diego CA, January 10-13th, 2005.

[4] http://www.islandnet.com/~see/weather/elements/lkefsnw3.htm

[5] http://www.glerl.noaa.gov

[6] http://www.umesc.usgs.gov/umesc_spatial/projects/gr_lakes_assessment/usfs_page.html

[7] http://www.csc.noaa.gov/crs/lca/greatlakes.html

STATSGO[8] and CANSIS[9] databases. The U.S. and Canada are presently putting in place a comprehensive GIS database for the Great Lakes.[10]

Elevation and land cover at a 1 km resolution and information on soil type at a 10 km resolution is however readily available from the Canadian Meteorological Centre and could be provided in GRIB format. 90m elevation data is also available freely (30m elevation data is available over the United States), but needs to be processed to obtain a complete, higher-resolution digital elevation model over the whole basin. Using elevation from the SRTM mission (available freely at a 90m resolution) is also a possibility over Canada.

List of Planned Deliverables (with Milestones):

Within the first year following the designation of the Great Lakes basin as an official HEPEX testbed, the Meteorological Service of Canada should be able :

1. to organize a workshop for researchers and user groups interested to contribute to the testbed
2. following this workshop, to produce a detailed plan of scientific and technology transfer activities
3. to put in place a quasi-operational ensemble hydrologic forecasting system fed by the NAEFS using the MEC/MESH community hydrologic prediction system (CHPS)
4. to make the CHPS and the forecasts available to the HEPEX community

These forecasts could then be used by the HEPEX community as a baseline to which other forecasts could be compared during the second year of the project.

List of Participants and Users:

Potential participants for this testbed include many divisions of Environment Canada (the Meteorological Service of Canada, the National Water Research Institute and the Water Survey), the Canadian Department of Fisheries and Oceans, the U.S. National Weather Service (the Office of Hydrologic Development and the river forecast centers), the Great Lakes Environmental Research Laboratory and Hydro-Québec research center. Potential users include the International St-Lawrence River Board of Control, the Ottawa River Regulation Planning Board[11] and the hydropower companies.

Given the socio-economic importance of the watershed, there are of course existing hydrological forecasting capabilities on many rivers of the basin. The GLERL already provides 48h deterministic forecasts of the water level of the Great Lakes through the Great Lakes Coastal Forecasting System (GLCFS)[12] and monthly forecasts of inflows and water levels through its Advanced Hydrologic Prediction System (AHPS)[13]. The Ottawa River Regulation Planning Board provides 7-day forecasts of the outflow of the Ottawa River routinely on a weekly basis and on a daily basis when required. Ensemble streamflow predictions based on a deterministic weather forecast are issued daily by

[8] http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/
[9] http://sis.agr.gc.ca/cansis/
[10] http://www.glfc.org/glgis/
[11] http://www.ottawariver.ca/
[12] http://www.glerl.noaa.gov/data/glfs/
[13] http://www.glerl.noaa.gov/wr/ahps/curfcst/

Hydro-Québec for many subwatersheds of the Ottawa River. To our knowledge, none of these systems use ensemble meteorological forecasts.

Test Bed 2: Southeast United States

Test Bed Leaders:

- Lifeng Luo (Princeton University)
- Eric F. Wood (Princeton University)

Test Bed Description:

The Southeast US was selected as the first region where realtime seasonal hydrologic forecasts are produced by the Princeton research group. It is also the region where the Southeast RFC is responsible for making short-term streamflow predictions. Within the region, there is the possibility to select several MOPEX basins for testing purposes. Because of ENSO and other possible teleconnections, the Southeast US seems to have certain predictability at seasonal timescale. As it is not a snow-dominant region, focus will naturally be on generating skillful and reliable meteorological forcing during the forecast period.

Key Scientific Questions:

Experiments at the Southeast US test bed will try to address the following HEPEX science questions:

1) How do we generate skillful and reliable meteorological forcing during the forecast period 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 forecast, teleconnection, be used reliably in seasonal hydrologic forecast?
4) How do we validate hydrologic ensembles for extreme events?

Key Objectives of the Research Project:

1) To test and compare different downscaling schemes in providing necessary atmospheric forcing to hydrological models for seasonal forecast
2) To develop methods for ingesting information from multiple sources to produce ensembles that reflects the natural uncertainties
3) To evaluate seasonal forecast and its usefulness for extreme events

Data Resources:

The following dataset are available fore the Southeast US test bed:

1) Land surface characteristics: including soil texture, topography, vegetation characteristics. These data are available for at 1/8-degree resolution. These data can be used to derive parameters used by individual model.
2) A 50-year daily 1/8-deg meteorological dataset is available. It contains daily precipitation and daily maximum and minimum temperature.
3) Long-term daily streamflow data are available from USGS for most of the streamflow gages.
4) Multiple climate model seasonal hindcasts (6-9 month) are available starting from 1958. These include NCEP CFS hindcast and ECMWF DEMETER hindcast.

The above dataset can be provided to the HEPEX community through our forecast website at http://hydrology.princeton.edu/forecast

List of Planned Deliverables (with Milestones):

1) Propose and implement different downscaling schemes (need contribution from the HEPEX community)
2) Compare forecasts from multiple downscaling schemes using multiple year hindcasts
3) Evaluate forecast skills for selected period/basin when/where extremes took place

List of Participants and Users:

1) Hydropower companies
2) Water quality modeling groups

Test Bed 3: Western US & British Columbian Basins

Test Bed Leaders:

- Frank Weber (BC Hydro, Burnaby, British Columbia, Canada)
- Andrew Wood (University of Washington, Seattle, USA)
- Thomas Pagano (USDA NRCS National Water and Climate Center, Portland, OR)

Test Bed Description:

The test bed targets hydrologic ensemble forecasting challenges that are particular to the orographically complex, snowmelt-driven basins of the Western US and British Columbia. Although this region presents water management difficulties ranging from flood prevention to multi-year reservoir operations, and streamflow forecasts are operationally produced for lead times from hours out to 2 years, the primary focus of this test-bed is on prediction at monthly to seasonal lead times (i.e., 2 weeks t0 12 months).

Several basins within this region are proposed for study:

- The Mica Basin (BC): Located at the headwaters of the Columbia River. As BC Hydro's second largest basin, it is significant not only for power production, but also for flood control as part of the Columbia River Treaty between Canada and the United States.
- Feather River (CA): Inflow to the primary water storage of the (CA) State Water Project, Lake Oroville, which supports a large variety of water uses.
- Columbia River sub-basins:
  - Yakima River (WA): Inflow to a number of reservoirs that support irrigation and fisheries; this east-slope Cascades mountain range basin is relatively vulnerable to warm winters.
  - Salmon River (ID): One of the larger relatively unimpaired basins in the western US, with snow playing a large role in summer runoff.
  - Upper Klamath River, OR: Inflow to Klamath Lake, the central project supporting Klamath River basin irrigation, fisheries, water quality and other demands.
- Gunnison River (CO): Inflow to the Aspinall Unit, collectively the largest surface storage project in Colorado and an important component in management of springtime flows for fish.

Key Scientific Questions:

The science questions for this test-bed focus on both the reduction and accurate estimation of hydrologic forecast uncertainties related to initial hydrologic state, hydrologic model error and climate forecasts. What strategies are appropriate for reducing uncertainty from each of the following sources:

- <u>Hydrologic model calibration:</u> does ensemble forecasting require different parameter estimation approaches than deterministic forecasting, such as multiple parameter sets or tailored objective functions? How can automatic calibration aid in characterizing uncertainty? Are improvements possible through multi-model combination or bias-correction techniques?
- <u>Initial conditions</u>: what are effective techniques for data assimilation of snow?

- Climate forecasts: how best to merge forecasts with different lead times, and to combine different types of forecast information (e.g., climate indices, climate model outputs)?

Also of interest, but of secondary priority, are questions concerning approaches for assimilation of soil moisture and streamflow (for initial condition estimation), and downscaling of climate model forecasts. Lastly, a related general question is: for different forecasting objectives (e.g., seasonal streamflow volume), how does the attribution of total forecast uncertainty in these three areas (model, initial state, climate forecast) vary in space and time?

Key Objectives of the Research Project:

This test-bed is intended to facilitate the comparison and evaluation of practical ensemble forecast related methods *that are viable in an operational setting*, and address current operational forecast difficulties. Because snow is such an important predictor in the western U.S. and British Columbia, insight into strategies for snow assimilation and the implications of snow assimilation for estimating forecast uncertainty and bias, is a high priority. Likewise, hydrologic model error reduction and estimation via calibration approaches are critical to the widespread operational deployment of hydrologic models in forecast operations, hence collaborative research in this area is strongly encouraged. Where initial conditions play less of a role (e.g., in the Klamath River basin), climate forecast related research is emphasized.

In each of the proposed basins, one or more of the questions are currently being addressed (incompletely) via various existing methods. The test-bed leaders will make available datasets and models related to those methods, and request that others in the community contribute alternative approaches (data, models, methods) for a parallel evaluation (retrospective, and if possible, in real-time).

Data Resources:

In general, the resources available for the six basins in the test-bed region are models, retrospective and in some cases real-time model inputs and outputs, verification datasets, and methods (programs and guidance in using them).

Existing resources for the Mica Basin:

- Calibrated conceptual hydrologic model (UBC watershed model)
- Model input: hydrometeorologic data available since 1965 (climate data: Golden, Blue River, Roger's Pass; flow data: Kinbasket Lake inflows; app. 20 snow courses and pillows).
- Model output: ESP forecasts are available since 1978.
- Archive of reference statistical forecasts.
- Methods for (a) merging short-lead and seasonal forecasts; and (b) snow assimilation – and data input/output for a retrospective application of these methods.

Existing or pending resources for the Salmon, Klamath, Yakima and Feather Rivers (and Mica and Gunnison R. basins):

- 1/8 degree model forcings (daily precip, tmin, tmax, wind speed) from 1915-present (by various methods).
- VIC model implementations in various stages of calibration and development.
- 1/8 degree VIC model outputs from 1915-present (by various methods), including runoff, evaporation, snow water equivalent and soil moisture.
- Naturalized monthly flow data for a number of locations; naturalized daily flow data for fewer.
- Real-time forecasts, once monthly (increasing to bi-monthly), since autumn 2003, from a variety of sources (NCEP and NSIPP1 climate models, ESP, CPC outlook), not all months present for all forecasts.
- Statistical downscaling methods for climate model ensemble output and CPC probability of exceedence format seasonal outlooks.
- A real-time/retrospective index station meteorology dataset (daily Prec, Tmax, Tmin, Wind speed).
- A VIC-specific SWE observation assimilation routine, and associated inputs/outputs in real-time (once a month) and retrospectively to winter 2002 or 2003 (depending on location).
- Calibrated PRMS models for the Klamath, Yakima and Gunnison river basins, with associated simulated and retrospective runs.
- Archive of historical official water supply outlooks.

List of Planned Deliverables (with Milestones):

Deliverables and milestones listed below primarily include research results related to the above questions and objectives that the team leaders expect to accomplish in the next 1-2 years.

- Evaluation of strategies for unbiasing seasonal streamflow forecasts (ESP or other).
- A comparison of several snow assimilation techniques for continuous simulation models.
- Evaluation of strategies for combining snow assimilation and additional bias-correction, in the context of ensemble forecasting.
- Evaluation of strategies for merging short and long term climate forecasts, and forecasts of different types.
- An improved understanding of the relative magnitudes of primary sources of forecast uncertainty (model, parameter, data, climate), especially as a function of season, regional climatology and measurable basin characteristics.

List of Participants and Users:

Current participants in this test bed include the University of Washington, the NRCS National Water and Climate Center (NWCC) and collaborators in the USGS, and BC Hydro (essentially, the testbed leaders institutions).

Potential users include:

- Bonneville Power Administration
- British Columbia River Forecast Center (Victoria)
- Feather River: CA DWR, California Energy Commission, State Water Project
- Klamath River: Klamath Falls Bureau of Reclamation Office

- Yakima River: Yakima Bureau of Reclamation Office, State of Washington Dept. of Ecology, Yakima Project irrigation districts
- Gunnison River: Upper Colorado Bureau of Reclamation Office, Upper Gunnison Water Conservancy District

Test Bed 4: Streamflow Forecasting in the Rio Grande Basin, Brazil

Test Bed Leaders:

- Professor Carlos Tucci (IPH/UFRGS, Porto Alegre, RS Brazil)
- Professor Walter Collischonn (IPH/UFRGS, Porto Alegre, RS Brazil)
- Professor Robin Clarke (IPH/UFRGS, Porto Alegre, RS Brazil)
- Professor Pedro Silva Dias (IAG, Universidade de São Paulo, Brazil)
- Dr Gilvan Sampaio de Oliveira, CPTEC/INPE, Brazil).

Test Bed Description:

The Rio Grande drains an area of about 145,000 km^2 of the Brazilian states of Minas Gerais and São Paulo, lying within a region roughly defined by 19^o to 22^o S and 43^o to 48^o W. The river is the main tributary of the River Paraná in its upper basin, and is used extensively for hydropower generation. Main hydropower installations are Marimbondo, Água Vermelha, Furnas and Estreito, each of which has installed capacity above 1,000 MW. In total, the Rio Grande basin has about 8,780 MW of installed capacity, which corresponds to approximately 12.3% of Brazil's hydropower installed capacity. Mean annual rainfall over the basin is approximately 1400 mm and is highly concentrated during 6 months from November to April.

Rainfall records of variable length and quality are available for 620 stations; flow records are available for 159 stations; and natural flows have been reconstructed for 19 sites extending back in some cases to 1931. Medium range forecasts (up to 15 days) and longer-term forecasts (up to a month or longer) are required for inflows into reservoirs from which hydropower is generated. Shorter-term forecasts (up to 7 days) are also of interest for local flood control purposes.

Key Scientific Questions:

The questions are (a) can models of atmospheric behaviour be combined with hydrologic rainfall-runoff models to diminish the uncertainty in forecasts of future reservoir inflows? (b) what is the uncertainty in forecasts obtained from this combined use, and how does this uncertainty compare with that of existing forecasting methods? (c) are SSTs useful for forecasting over the longer term (a month ahead or longer), and if so, can such forecasts be combined in any way (e.g., by Bayesian methods) with quantitative forecasts from regional climate models?

Key Objectives of the Research Project:

(a) To explore the use of ensembles produced by the CPTEC model of global climate (CPTEC: Centro de Previsão de Tempo e Clima), for medium and longer-term forecasting, as input to a finer-scale (40 km grid squares) regional climate model (RAMS: Regional Atmospheric Modelling System) used by the University of São Paulo.

(b) To explore the use of forecasts produced by RAMS as inputs to the Hydrological Model for Large Basins developed at the Instituto de Pesquisas Hidráulicas, Porto Alegre, Brazil, for the purpose of predicting flows in the Rio Grande watershed, with lead-times extending up to a month and longer.

(c) To explore short-term rainfall forecasts from the operational ETA model of CPTEC as input to the Large Basins Hydrological model for the purpose of forecasting inflows to the most important reservoirs in the Rio Grande basin with lead times of up to 12 days.

Data Resources:

Hydrological data for the watershed are available to the HEPEX community from the following site:

http://galileu.iph.ufrgs.br/collischonn/ClimaRH/principal.htm

List of Planned Deliverables (with Milestones):

Deliverable expected by March 2006: combined atmospheric model (RAMS, with boundary conditions determined by CPTEC-COLA GCM) with the large-basin hydrological model developed by IPH (Instituto de Pesquisas Hidráulicas).

List of Participants and Users:

Improved forecasts will be of particular value to Brazilian agencies concerned with power generation and strategic planning of power supply: notably ANEEL (Agência Nacional de Energia Elétrica) and ONS (Operador Nacional do Sistema Elétrico). Methodologies developed for the test-bed watershed could have application in other regions of Brazil an possibly more widely in South American countries where hydropower generation is important for national economies. At present, flow forecasts used by ONS do not utilize knowledge either of rain that has already fallen, or of forecasts of future rainfall.

Test Bed 5: Model Uncertainty

Test Bed Leaders:

- Martyn Clark (CIRES, University of Colorado)
- Jasper Vrugt (Los Alamos National Laboratory)?
- Hamid Moradkhani (University of California, Irvine)?

Test Bed Description:

- **Basins:** TBD; suggest a subset of the MOPEX basins, scattered across diverse climate regimes.

- **Space/time scales of interest:** Basins ranging in size from ~500 to 20,000 km^2; initially just model simulation, but with a view to streamflow forecasts at lead times from days through to seasons.

Key Scientific Questions:

What are the advantages and limitations of different methods for characterizing and reducing uncertainty in hydrologic model simulations?

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. Characterization of uncertainty may be accomplished through ensemble methods; reduction of uncertainty may be accomplished with data assimilation methods.

Experimental Design:

- **Characterizing model uncertainty (e.g., ensemble model simulations)**
  Test bed participants will be asked to produce estimates of uncertainty of each model state variable and model flux at each model time step and each sub-basin. Participants should provide model output in a prearranged format (e.g., NetCDF files containing all model states and fluxes with dimension (time, sub-basin, ensemble member) or dimension (time, sub-basin, mean, variance). These files may be used for the data assimilation task.

- **Data assimilation**
  Test bed participants will be asked to update model simulations with observations of streamflow and snow water equivalent. Participants should provide (i) estimates of errors in observations; and (ii) estimates of the mean and uncertainty in each model state variable and model flux. Participants should provide output in an identical format to the uncertainty files.

Data Resources:

Test bed leaders will provide a hydrologic model (e.g., the distributed SNOW-17/Sacramento model) configured for several basins in different climate regimes (e.g., DMIP basins, MOPEX basins, etc.). This will include the input datasets (prcp, temp), ancillary datasets on soils, vegetation, etc., and the topology of the channel network. This model will be configured as a "black-box" with wrappers around it.

List of Deliverables (with Milestones):

- 1st December 2005: Test-bed leaders provide data/models/documentation provided to test-bed participants
- 1st May 2006: Participants produce CF-compliant NetCDF files to test-bed leaders
- 1st June 2006: Test-bed leaders produce summary verification statistics for precipitation, temperature, and streamflow
- 1st August 2006: Participants produce revised output files, and deposit code on the HEPEX web site
- 1st October 2006: Submission of two-part paper summarizing test-bed results (all participants will be included as authors).

List of Participants and Users:

- Participants: Ajami (UC-Irvine); Clark (Univ. Colorado); Duan (Lawrence-Livermore); Hopson (NCAR); Lettenmaier group (UW); Moradkhani (UC-Irvine); Seo (NWS/HL); Vrugt (Los Alamos); Wood/Luo (Princeton).
- Users NWS RFCs and other forecasting agencies worldwide.

Test Bed 6: Po Catchment in Italy, Europe

Test Bed Leader(s):

- Jutta Thielen (Joint Research Centre, European Commission)
- Stefano Tibaldi (ARPA, Bologna)

Test Bed Description:

The Po river basin is situated in Northern Italy and covers an area of ca. 73,000 km^2. The Po River is the largest Italian river and 15 million people live within its reach (population densities up to 1500 inhabitants/km^2). The Po basin includes several Italian regions: Piemonte, Lombardia, Valle d'Aosta, Emilia Romagna, Liguria, Trento and small parts of Veneto. It's main flow direction is west to east crossing whole Northern Italy and flowing into the Adriatic Sea. It has a total length of 650 km stretching from its headwaters, at 2000 m of elevation, in the south-west of the Piemonte region, close to France, through all of Northern Italy passing the city of Torino, coming close to Alessandria, Pavia, Piacenza, Cremona and Ferrara to the Adriatic Sea. The Po has 141 tributaries, the biggest are Tanaro, Ticino, Sesia, Adda, Oglio and Dora Baltea and the surface water use in the region exceeds 25 billion m^3/a. In the alpine part of the catchment there are three big lakes : Lago Maggiore, Lago di Como and Lago di Garda.

A brief description of the forecasting space/time scales of interest:

- medium-range weather and flood forecasting up to 10-15 days

Key Scientific Questions:

- removing bias from meteorological forecasting data
- medium range probabilistic flood forecasting
- usefulness of meteorological ensemble approach for QPF in improving flood forecasting

Key Objectives of the Research Project:

Test simplistic routines for bias removal in an area such as Northern Italy that is dominated by important orography (Alps) and for which the weather forecasting models have problems to produce reliable quantitative rainfall forecasts. The test bed leaders would like to test bias removal routines proposed for Bangladesh for this region. The method will be applied for both the deterministic and the probabilistic weather forecasts.

Methods for flood forecasting based on threshold exceedances are being developed by the JRC within the framework of the European Flood Alert System and could be tested for the Po also by other researchers. Availability of quasi-real time ensemble high-resolution limited-area model quantitative precipitation forecasts in the Po Valley and alpine region will be exploited to test their usefulness in improving reliability of flood forecasting models and techniques.

Data Resources:

- GIS information on the catchment including DEM (1km), land use (1km) , soil data (1:1M), river network (1km, 5km)

- Discharge data at selected stations for a time period from 1995-present
  - Ca. 10 x 3 discharge stations (with rating curves) for the 10 major tributaries to the Po River
  - 4-6 discharge stations (with rating curves) for the main Po River

- Meteorological data on
  - rainfall, evaporation and temperature on gridded fields (JRC MARS) from 1995-present
  - rainfall and temperature point data (ARPA) from 1995-present :
    - time resolution daily ca. 1000 stations
    - time resolution hourly ca. 500 stations
  - ensemble Limited-area model forecasts (QPF) from 2003-present

The data could be provided on an ftp –site accessible to the HEPEX community.

List of Planned Deliverables (with Milestones):

- Preparation of data and making available (end of the year)
- Testing on bias removal for meteorological forecasts (mid next year)

List of Participants and Users:

- ARPA-ER Serv. IdroMeteo, (S. Tibaldi, S. Pecora)
- JRC (J. Thielen)
- Università di Bologna (E. Todini)
- University of Colorado (T. Hopson)
- Lancaster University (F. Pappenberger)

Test Bed 7: Brahmaputra and Ganges Basins

Test Bed Leaders:

- Thomas Hopson (University of Colorado)
- Peter Webster (Georgia Tech)

Test Bed Description:

The Brahmaputra and Ganges river basins are part of the project Climate Forecasting Applications for Bangladesh (CFAB), which provides operational real-time forecasts of river discharge into Bangladesh at daily, weekly, monthly, and seasonal time-scales. In support of this project, short-term (1 to 10 day) forecasts of severe flood-stage discharges in the catchments of the Ganges and Brahmaputra Basins were developed and began operational dissemination during the monsoon season of 2003, continuing to the present. In order to generate fully automated probabilistic river discharge forecasts, the forecasting scheme utilizes the European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble weather forecasts, near-real-time satellite and rain gauge precipitation estimates, and near-real-time discharge estimates from the Bangladesh Flood Forecasting and Warning Centre (FFWC), in conjunction with statistical dressing and the use of lumped and distributed hydrological models.

The spatial scale of the Brahmaputra basin is approximately 1×10^6 km^2 while that of the Ganges basin is approximately 5×10^5 km^2. The temporal scale (response time) of the Brahmaputra and Ganges basins are approximately 10 days and 20 days, respectively.

Key Scientific Questions:

- Can data assimilation techniques significant improve in operational discharge forecast performance through improvements in forecast model state estimation?

- What role does data assimilation technique play in provide accurate forecast error estimates, reducing hydrologic model parameter uncertainty, and improving model structural calibration in rain-fed and snow-melt dominated basins?

Key Objectives for the Research Project:

The Brahmaputra and Ganges Test Beds will provide an opportunity to compare the performance of a variety of different data assimilation techniques within this data-sparse operational setting. In particular, these two basins are primarily ungauged, except at the forecast location itself, where near-real-time discharge estimates (rating curve derived) are available. As well, the only "observation-based" data inputs are "forcing" precipitation data provided by two semi-independent near-real-time satellite-derived estimates (6 to 12 hour lags) as well as sparse rain gauge estimates (36 hour lag).

As part of the data assimilation technique inter-comparison, the current operational discharge forecast methodology for these basins includes an analogue-based data assimilation and forecast correction technique. This technique was developed to provide real-time estimates of discharge forecast uncertainty by utilizing the near-real-time discharge estimates. This technique has shown good skill, and has its own strengths and weaknesses not inherent in other data-assimilation techniques.

Data Resources:

Data Sets

- Daily River Discharge of the Brahmaputra and Ganges Rivers derived from rating curves from the late 1950's to the present.

- ECMWF ensemble forecast weather variables [10U 10V 2D 2T CP LSP SLHF SSHF SSR STR SWVL1 SWVL2 SWVL3 SWVL4] over the region 30E to 160E, 40S to 45N, nominally 1°×1°, but linearly interpolated down to 0.5°×0.5°, 51 members, initialized 12:00 GMT, with forecast interval times every 12 hours out to 10 days from 2003 to the present.

- Satellite observed precipitation from the Global Precipitation Climatology Project (GPCP) and the NOAA CPC Morphing Technique ("CMORPH"), 3 hourly, nominally 1997 to the present.

- Gridded rain gauge data, 1979 to the present, provided by the National Oceanic and Atmospheric Administration's Climate Prediction Center, which were derived from the daily-reporting GTS rain gauge network.

- The satellite and rain gauge estimates are also combined into one product and are interpolated to the same grid (0.5°×0.5°) and time window as the ECMWF forecasts for operational use.

- Digital Elevation Map over the region from the EROS Data Center.

Forecasting Techniques

- A weather forecast correction technique is available for precipitation forecasts to remove model biases and other discrepancies with "observations" (while retaining spatial and temporal covariances). The correction approach is based on a quantile-to-quantile mapping technique.

- A flexible multi-model discharge forecasting approach, which combines a data-based lumped catchment model and a sub-catchment distributed model, has been implemented for real-time forecasting.

- An analogue technique is available to account for all aspects of discharge forecasting error (while simultaneously making a model correction) so that more statistically correct probabilistic discharge forecasts can be made.

List of Project Deliverables (with Milestones):

- Discussions of current data-assimilation techniques useful to the Brahmaputra and Ganges watersheds would occur through the end of 2005

- Implementation of the techniques within the operational structure to begin January 2006

- Monsoon season, 2006 (June), application of the techniques operationally (daily) throughout the season (ending October).

List of Participants and Users:

- Participants: Thomas Hopson (thomas.hopson@colorado.edu) and Peter Webster (pjw@eas.gatech.edu) of CFAB; Roberto Buizza and ECMWF, who would provide ECMWF's medium-range ensemble forecasts to this project; and those others within the HEPEX community interested in collaborative data assimilation code development within an operational setting.

- Users: Country of Bangladesh; any improved forecasting techniques would be implemented operationally as part of CFAB's country-wide disseminated flood forecasts.

Test Bed 9: Statistical Downscaling

Test Bed Leaders:

- Martyn Clark (CIRES, University of Colorado)
- John Schaake (NWS Hydrology Laboratory)

Test Bed Description:

- **Basins:** TBD; suggest a subset of the MOPEX basins, scattered across diverse climate regimes.

- **Space/time scales of interest:** Seek to produce forecasts at individual stations at lead times of 1-14 days. These would be used to produce streamflow forecasts at basins ranging in size from ~500 to 20,000 km^2

Key Scientific Question:

What are the advantages and limitations of different methods for extracting information from Numerical Weather Prediction models, for the purposes of forecasting streamflow?

Key Objectives of the Research Project:

- 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
- Identify the MRF output variables that can be used to provide sub-grid information—for example, wind and humidity output can be used in a statistical model to replicate orographic precipitation processes, and provide local-scale information that is not present in the raw precipitation output [Clark and Hay (2004) have a table that summarizes the frequency that different variables are used in their regression equations].
- Identify of the sample size required to reliably forecast precipitation, temperature, and streamflow, for different thresholds.

Experimental Design:

Participants will be asked to "downscale" the CDC MRF Reforecast Dataset to produce ensemble precipitation and temperature estimates at individual stations for the selected test basins. Participants should provide downscaled MRF output in a prearranged format (e.g., CF-compliant NetCDF files). The format may be a separate file for each station that has a structure with two variables (precipitation and temperature) with dimensions (forecast initialization time, forecast lead time, ensemble member).

The downscaled MRF output will be used as input to a hydrologic model to produce forecasts of streamflow (suggest using the distributed version of the SNOW-17/ Sacramento model, but any model can be used). This model will include a prearranged method to distribute the downscaled precipitation and temperature estimates across a basin. The model will be configured so it can be run as a "black box" by any of the testbed participants to produce NetCDF ensemble streamflow forecast output (i.e., with identical dimensions to the downscaled model input files produced by the participants). The hydrological model can be run by the testbed leaders, if desired.

Test-bed leaders will compute the following verification statistics:

- Climatological Bias
- Climatological space/time/inter-variable correlations
- Reliability, Discrimination for different thresholds
- Brier Skill Score for different thresholds
- Ranked Probability Skill Score
- Ranked Histogram
- Relationships between ensemble spread and forecast skill

Data Resources:

Test-bed leaders will provide:

- CDC Reforecast model output for the selected test basins, and example code to read it
- Station data for the selected test basins, and example code to read it
- Example code to define the NetCDF output files (i.e., those files produced by the test-bed participants, that contain ensemble downscaled output at individual stations)
- The hydrologic model, with wrappers around it, so it can read the NetCDF output files and produce forecasts of streamflow
- Verification code that reads the NetCDF output files and computes verification statistics.
- Plotting routines

Note that participants have no responsibility to run the hydrological model and compute verification statistics themselves. If participants do perform these tasks as part of their methodological development, they are encouraged to document their modifications thoroughly.

List of Planned Deliverables (with Milestones):

- 1st December 2005: Test-bed leaders provide data/models/documentation provided to test-bed participants
- 1st May 2006: Participants produce CF-compliant NetCDF files to test-bed leaders
- 1st June 2006: Test-bed leaders produce summary verification statistics for precipitation, temperature, and streamflow
- 1st August 2006: Participants produce revised output files, and deposit code on the HEPEX web site
- 1st October 2006: Submission of two-part paper summarizing test-bed results (all participants will be included as authors).

List of Participants and Users:

Participants: Bradley (U. Iowa); Clark (Univ. Colorado); Hamill (CDC).

7. MEETING AGENDA

The 2nd HEPEX Workshop was held on 19-22 July 2005 at the NCAR Foothills Laboratory in Boulder, Colorado. Over the first three days, oral and poster presentations were made on the topics of (1) weather and climate forecasting for hydrologic predictions, (2) data assimilation and modeling techniques for hydrometeorological prediction, and (3) meteo- and hydrological applications. Two breakout sessions were held for Working Group meetings, and plenary sessions were held to discuss of Working Group recommendations and make proposals for HEPEX Test Beds. On Friday 22 July, an open HEPEX planning meeting was held.

This section lists the complete agenda for the meeting. The meeting agenda is also available online, with links to the presentations, from the HEPEX web site at:

http://hydis8.eng.uci.edu/hepex/scndwksp/scndwksp.html

Day 1: Tuesday, 19 July

8:30 am **WELCOMING REMARKS, OBJECTIVE, AND SCHEDULE**
(John Schaake, Roberto Buizza, Martyn Clark, and Tom Hamill)

8:45 am John Schaake and Roberto Buizza: An overview of the Hydrological Ensemble Prediction EXperiment (HEPEX)

SESSION 1: Weather and climate forecasting for hydrologic predictions
Chair - Tom Hamill

9:15 am Zoltan Toth and L. LeFaivre: Hydrologic applications of the North American Ensemble Forecast System

9:30 am Tom Hamill and Jeff Whitaker: Using reforecasts to calibrate probabilistic weather predictions

9:45 am Roberto Buizza, David Richardson, Renate Hagedorn, and Philipe Bougeault: TIGGE (the THORPEX Interactive Grand Global Ensemble)

10:30 am Shaleen Jain and Gary T. Bates: Predictability of spring warmups, snowmelt and streamflow peaks in western United States: Prospects for the use of CDC Reforecast Ensembles

10:45 am Steve Mullen, Matt Wandishin, Mike Baldwin, and John Cortinas: Short-range ensemble forecasts of precipitation type

11:00 am Ray Arritt, Bill Gutowski, and E. S. Takle: Multi-model ensembles for seasonal prediction of precipitation

SESSION 2: Data assimilation and modeling techniques for hydrometeorological prediction
Chair – Andrew Slater

1:15 pm Newsha Ajami: Confronting total uncertainty in Hydrologic Prediction: An Integrated Bayesian Multi-Model Hydrologic Ensemble Prediction System

1:30 pm Milija Zupanski: Non-Gaussian error statistics and ensemble data assimilation

1:45 pm Dusanka Zupanski: Can we estimate and reduce major sources of forecast uncertainties employing a unified framework?

2:00 pm Tom Hopson and P. Webster: Operational Short-term Flood Forecasting for Bangladesh: Application of ECMWF Ensemble Precipitation Forecasts

2:45 pm DISCUSSION of the charge given to working groups

3:00 pm Working Groups

Day 2: Wednesday, 20 July

8:30 am REPORTS FROM WORKING GROUPS / DISCUSSION

SESSION 2: Data assimilation and modeling techniques for hydrometeorological prediction (continued)
Chair – Andrew Slater

9:45 am Hamid Moradkhani: Another View to Hydrologic Ensemble Prediction via Sequential Monte Carlo Methods

10:30 am Jasper Vrugt: Real-time Data Assimilation for Operational Ensemble Streamflow Forecasting

10:45 am Andrew Slater: Snow data assimilation via an ensemble Kalman filter

SESSION 3: Meteo- and hydrological applications
Chair- Kristie Franz

1:15 pm David Kingsmill, Brooks Martner, Jessica Lundquist, Dave Jorgensen, Ken Howard, Steve Koch, and Paul Schultz: The NOAA Hydrometeorological Testbed Program: overview and progress to date

1:30 pm Kevin Werner and Dave Brandon: Experimental forecast techniques at the CBRFC

1:45 pm Lifeng Luo: A realtime seasonal hydrologic forecast system for the eastern US

2:00 pm Jutta Thielen-del Pozo, M.H. Ramos, J. Bartholmes, B. Gouweleeuw, F. Pappenberger, GF Franchello, J. v.d.v Knijff, and A. de Roo: Making use of flood ensemble prediction system in the European Flood Alert System (EFAS)

2:30 pm Kristie Franz, John Schaake, Roberto Buizza, Steve Mullen : Proposal of a THORPEX/HEPEX Hydrologic Applications Project (THEPS)

3:15 pm BREAKOUT GROUPS

Day 3: Thursday, 21 July

SESSION 3: Meteo- and hydrological applications (continued)
Chair- Kevin Werner

8:30 am Robert K. Hartman: Use of Weather and Climate Forecast Information in the California-Nevada River Forecast Center (CNRFC)

8:45 am Allen Bradley and John Schaake: GAPP Ensemble Experiments Initiative

9:00 am Martyn Clark: Streamflow forecasting in snowmelt-dominated basins

9:15 am V. Fortin, A. Pietroniro and P. Pellerin: A Canadian Community Hydrologic Prediction System

9:30 am Andrea J. Ray and Robert S. Webb: Hydrologic predictions in the context of regional decision support systems: User studies

9:45 am Lauren Hay, Martyn Clark, and George Leavesley: Hydrologic Predictability in Mountainous Terrain

10:30 am Andrew Wood, Theodore Bohn, Ali Akanda, and Dennis Lettenmaier: A multimodel hydrologic ensemble for seasonal streamflow forecasting in the western U.S.

10:45 am Carlos Tucci: Flow Forecasting in Large Basins in Brazil

11:00 am Thomas Pagano, Jennifer Erxleben, Tom Perkins, Phil Pasteris: Operational Simulation Model Forecasting at the NRCS National Water and Climate

11:15 am Balaji Rajagopalan, Martyn Clark, Katrina Grantz, Satish Regonda: Incorporating Large-Scale Climate Information in Water Resources

11:30 am John Schaake: Ensemble Streamflow Prediction by the National Weather Service (NWS)

11:45 am M Gopalakrishna: HEPEX – Perspectives of users and their anticipations

2:00 pm PLENARY SESSION

Day 4: Friday, 22 July: Special HEPEX planning meeting

9:00 am Planning Meeting

Agenda items:

(1) Current HEPEX status
(2) User perspectives
(3) HEPEX/TIGGE interaction
(4) Regional HEPEX projects
(5) Supporting data sets
(6) Evolution of coupled forecasting system
(7) Publications resulting from the workshop
(8) Future workshops, special sessions, and other activities
(9) HEPEX organization
(10) Milestones
(11) Action Items

12:00 pm MEETING ADJOURNS

Posters:

Kevin Werner and Dave Brandon : Using CFS model output in the NWSRFS

M. Saïd, A.-C. Favre, H. Massé, V. Fortin, L. Perreault, N. Evora: Using Bayesian Model Averaging to calibrate meteorological forecast ensembles: Application to the forecasts of Environment Canada

Luc Perreault, Noël Dacruz Evora, Anne-Catherine Favre, and Vincent Fortin: Experimenting calibration methods on Canadian meteorological ensemble forecasts for uncertainty assessment of Hydro-Quebec streamflow predictions

Allen Bradley, Anton Kruger, and Stuart Schwartz : Verification of AHPS Ensemble Streamflow Predictions for the North Central River Forecast Center

Huiling Yuan: Calibration of Probabilistic Quantitative Precipitation Forecasts from the NCEP RSM system over Hydrologic Regions

Kristie Franz: Snow model evaluations for ensemble streamflow forecasting