HEPEX
Hydrologic Ensemble Prediction EXperiment

THORPEX/HEPEX HYDROLOGICAL ENSEMBLE PREDICTION SYSTEM (THEPS)

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Note: This document was endorsed at the Special Topics Workshop on Downscaling of Atmospheric Forecasts for Hydrologic Prediction, June 15-18, 2009, Toulouse, France. However, we are committed to update it regularly. Please email any comments to *florian.pappenberger@ecmwf.int*.

This document outlines the case for a hydrological component based on the HEPEX project within the THORPEX project. First it describes the THORPEX and HEPEX, and outlines the research questions both face. It then elaborates on the potential of hydrology to enrich and enhance the THORPEX scientific goals. This is followed by a specific section on TIGGE and GIFS. Finally, a list of goals and an implementation plan is presented.

Background

THORPEX

THORPEX is a World Weather Research Programme which aims to accelerate improvements in the accuracy of weather forecasts, from 1 day to 2 weeks, in particular by demonstrating the effectiveness of a multinational, multi-model Meteorological Ensemble Prediction System (meteorological EPS). The THORPEX research pan is subdivided into four sub-programs:

1. *global-to-regional influences on the evolution and predictability of weather systems*. Research Topics: Assess predictive skill at all forecast ranges, including potential predictability; Quantify the contributions of initial condition and model uncertainty to forecast errors; Investigate the relative effects of small and large-scale initial-condition uncertainty ; Develop improved global ensemble-prediction systems; Utilize global ensemble prediction systems to specify boundary conditions for high-resolution regional ensemble forecasts
2. *global observing-system design and demonstration*. Research Topics: Improve background-error covariances in existing assimilation schemes; Develop methods for cycling flow-dependent background errors; Develop adaptive quality control; Incorporate model uncertainty into data assimilation procedures; Targeting strategies; Improved use of observations; Quantification of observation errors

(with OS group)

3. *targeting and assimilation of observations*. Research Topics: Explore potential for new observing systems that improve skill of high-impact forecasts; innovative technologies; airborne prototypes of next-generation spaced based remote-sensing systems; advanced data processing methods (thinning, super-obbing); Collaboration with data assimilation on OSSEs, OSEs, characterizing observation error (with DAOS).
4. *societal, economic, and environmental benefits of improved forecasts*. Research Topics: Identify high-impact weather forecasts; Assess the impact of improved forecast systems; Develop advanced forecast verification measures ;Develop new user-specific weather products

HEPEX

The Hydrologic Ensemble Prediction EXperiment (HEPEX) is an international effort that brings together hydrological and meteorological communities from around the globe to build a research project focused on advancing probabilistic hydrologic forecast techniques. The HEPEX mission is to demonstrate how to produce reliable Hydrological Ensemble Predictions (Hydrological EPSs) that can be used with confidence by emergency management and water resources sectors to make decisions that have important consequences for economy, public health and safety.

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 ensemble 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?

HEPEX is organized around test beds. 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 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 for community experiments to address the questions, and are expected to include active user participation. Proposals for eight test bed projects were presented at the second HEPEX workshop. Participation in HEPEX is open to anyone wishing to contribute to its objectives. Individuals interested in becoming involved in HEPEX can do so as a member

of the HEPEX Science Steering Group, User Council, or an affiliated international organization, or through participation in the HEPEX projects and activities. Primary leadership of the HEPEX project will be the responsibility of the science steering group. The User Council will oversee HEPEX activities. Scientists and users will formulate projects and activities to assure that user needs, as well as science issues, are addressed. HEPEX activities will include test beds, intercomparison experiments, workshops, and meetings.

Contribution of HEPEX to THORPEX

HEPEX can contribute to a wide range of THORPEX goals and research topics.

Global-to-regional influences on the evolution and predictability of weather system

Hydrological applications range across scales from catchments of less than a few sqm to continental scale. It can integrate responses over a range of variables (for example precipitation, evaporation, temperature, radiation etc) as well as across spatial and temporal scale. Hydrological systems act often as a low pass non-linear filter of atmospheric drivers. As such it can for example allow to assess *predictive skill at all forecast ranges, including potential predictability* of many near surface variables on a large range of scales. These scales are meaningful integrators of point observations and thus allow a suitable comparison to model predictions. Additionally, hydrology can act as a diagnostic *to quantify the contributions of initial condition* and *model uncertainty to forecast errors or investigate the relative effects of small and large-scale initial-condition uncertainty* and as such *develop improved global ensemble-prediction systems*. For example, many hydrological regimes can be sensitive to initial conditions and evaluate the signal of changing configurations. Additionally, hydrological models are already part of many meteorological models in the form of land surface schemes. HEPS can act as a communication platform between the traditional small scale hydrological community and the large scale hydrologists.

Data assimilation

Land surface analysis systems used in NWP are decoupled from the atmospheric analysis. They mainly rely on SYNOP data for screen level atmospheric parameters analysis (2m temperature and relative humidity) and snow analysis. Soil moisture is analysed based on screen level atmospheric parameters analysis using either an optimum interpolation approach (ECMWF, CMC, Météo-France) or a simplified EKF approach (DWD). New generations of Earth observation satellites will be suitable for NRT monitoring of land surface variables (eg SMOS, ASCAT, SENTINEL,...). They are expected to drastically increase the amount (spatial and temporal coverage/sampling) and relevance of data to be used for land surface analysis in NWP. Soil moisture and snow are of particular interest since they are at the interface between the atmospheric and the

surface branches of the hydrological cycle. Current activities conducted in particular at ECMWF, CMC and Météo-France focus on developing the use of satellite data for soil moisture analysis. These systems are expected to be extended to snow analysis and vegetation parameters analysis in the near future. They will provide a comprehensive land surface data assimilation system suitable for the purpose of consistent NWP and hydrological forecasting.

Societal, economic, and environmental benefits of improved forecasts

Identify high-impact weather forecasts; Assess the impact of improved forecast systems; Develop advanced forecast verification measures ;Develop new user-specific weather products

Hydrology is important for a large range of high impact weathers such as floods, draughts, peat and forest fires etc. It allows a easy and user focused way to *identify high-impact weather forecasts* and *assess the impact of improved forecast systems*. Stakeholder targeted advanced verification methods can be easily developed for example by aggregating of data to endusers targeted units, e.g. river basins, sub-units, and the development of corresponding methodologies. Hydrologists have considerable experience on aggregating, interpolation and error analysis of for example rainfall fields. An exchange of knowledge could be beneficial for both sides. A strong interface between the hydrological and meteorological community would foster applications of the meteo forecasts in hydrology and lead to *new user specific weather products*.

TIGGE and GIFS

One of the accomplishments of THORPEX has been the development of the THORPEX Interactive Grand Global Ensemble (TIGGE), which allows researchers to access from a single repository an archive of ensemble forecasts provided by different meteorological centers around the world. Research conducted in TIGGE will be used to guide the design and development of the Global Interactive Forecasting System (GIFS). The TIGGE archive contains metrological EPS and high resolution forecast from over 10 global forecasting systems. The archive starts in October 2006 and centres have been added consequentially. Most variables which are important for hydrological forecast have ben achieved.

Issues

As mentioned in the international research implementation plan of THORPEX, HEPEX is a major potential application of TIGGE (p.39). However:

1. **Past Meteorological EPS and corresponding meteorological observations are required.** An Hydrological EPS typically requires that atmospheric forecasts are

downscaled in order to have the same climatology as the atmospheric forcings that was used for its calibration and local effects (which includes not only the marginal distribution for each forcing variable, but typically the joint distribution of all forcing variables for all lead times and all watersheds of interest). Calibrating ensemble forecasts for hydrological applications is thus a daunting task which relies on a sample of past forecasts of the meteorological EPS and corresponding meteorological observations.

2. **A long record of forecasts are required for using Hydrological EPS for flood warning.** Hydrological EPSs can have tremendous value for issuing early flood warnings. However, on a given basin, floods are typically rare events. In order to verify a Hydrological EPS and demonstrate its usefulness for flood warning on a given watershed, it is thus required to have access to forecasts for past events, which in turn may require a record of Hydrological EPS forecasts more than a decade old. To achieve this goal consistent meteorological forecasts are needed, meaning, that long time series are required for which only a small (preferably none) change in error structure of the predictors of the numerical weather prediction models occurs.

3. **The TIGGE archive is new and thus very short.** Through TIGGE, researchers only have access to a short archive of ensemble forecasts from multiple centers (achieving starts in October 2006), which is insufficient to rigourously calibrate downscaling methods or demonstrate the usefulness of a Hydrological EPS based on TIGGE. Furthermore, the individual Meteorological EPS which are contributing to TIGGE evolve continuously, and so do the corresponding model climatologies. Thus, currently, the archive of past forecasts can be problematic to use for downscaling purposes. An established THEPS group could establish protocols to improve these shortcommings**.** In order to provide feedback to the THORPEX community on the design and development of GIFS, the HEPEX community has to start to use the TIGGE dataset now, and cannot wait for the availability of a sufficiently long archive of past forecasts

4. **Access to and manipulation of Hydrological EPS data is practically complicated for many hydrologists.** Data access can be a problem: while Hydrological EPS may require a large amount of data for calibration, the design of a Hydrological EPS will only require meteorological information over the watersheds of interest. Furthermore, the hydrological forecasting community is currently not geared to use the standard binary file formats which are commonly used in meteorology, such as GRIB. While this may look like a minor issue, in practice it can significantly slow down research, development and implementation of Hydrological EPSs.

Goals

The THEPS project has three goals:

1. Assess how the TIGGE datasets and THORPEX science plan can meet the requirements of the HEPEX community.

2. Provide feedback to the THORPEX community on the information content of TIGGE and THORPEX scientific questions , and hence contribute to the design and development of GIFS.

3. Help the HEPEX community in using the TIGGE datasets and THROPEX research outputs within Hydrological EPSs.

Avenues for THORPEX-HEPEX cooperation.

- Use TIGGE data sets to evaluate their value for hydro forecasts, and compare against reforecast-based techniques.

- Use THORPEX-HEPEX interaction as a vehicle for the dynamical-statistical downscaling comparisons that we know need to be done.

- Use the existing HEPEX test bed data in these comparisons.

- Validation / verification tools can be shared between the communities, leading to greater trustworthiness of results and comparisons; expand hydro tools to be able to do grid or weather obs based verification, or share weather tools.

- TIGGE data format (grib; netCDF) not easily usable in hydro community, also because of file size; can folks who pioneer their use feed back their algorithms to the TIGGE archive centers to make it easier for others to use?

Implementation plan

In order to meet the goals that we have set to address the different issues related to the use of the TIGGE datasets by the HEPEX community, we propose the following strategy:

1. Identify THORPEX working groups and interests groups which are critical for meeting THEPS objectives, and engage these. Encourage individual hydrological researchers to engage with the THORPEX science plan and research outputs to demonstrate benefit of hydrological applications within the THORPEX program. Formulate a set of hydrological relevant scientific questions which accompany and complement the THORPEX science plan particular questions which can be addressed with the TIGGE archieve

2. Provide, in a way that is as user friendly as possible, all ensemble forecasts from

the TIGGE database, together with the verifying observations (both meteorological and hydrological), for a number of watersheds which cover a wide range of possible applications.

3. Encourage hydrological researchers to use the TIGGE database for the development of methodologies adapted to the current constraints of the TIGGE dataset, and to report on their successes as well as on their difficulties to the HEPEX community and to the THEPS project.

4. Promote benefits of a strong hydrological competence at meteorological centers and vice versa, which would help in achieving not only THORPEX goals but also objectives of the individual centres

5. Link with the HEPEX verification testbed in order to provide researchers with tools which can be used efficiently to compare different methodologies for making use of the TIGGE dataset and the THORPEX science plan.

6. Document pf lessons learned. Assess what would be required for the TIGGE dataset and Thorpex research program to be more useful for the HEPEX community, ideally by quantifying the expected gains. For the purpose of TIGGE, other atmospheric forecasts database can be used, such as NCEP and ECMWF ensemble reforecast experiments, and the GEWEX forecast database.

7. Report regularly on the progress made to the THORPEX and HEPEX communities, by way of a web site and by attending workshops and conferences organized by these two communities. In particular, present the THEPS project at the upcoming THORPEX meeting in Monterey (May 2009) and at the upcoming HEPEX meeting in Toulouse (June 2009). Organize a THEPS session at an international conference to promote the project and share results within two years.

8. Review the implementation plan annually, by way of an informal scientific advisory panel.