WORKSHOP ON POST-PROCESSING AND DOWNSCALING OF ATMOSPHERIC ENSEMBLE FORECASTS FOR HYDROLOGIC APPLICATIONS

15-18 June, Toulouse, France

BOOK OF ABSTRACTS

HEPEX Hydrologic Ensemble Prediction EXperiment

cost 731

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METEO FRANCE Toujours un temps d'avance

1. Ensemble weather forecasting at BC Hydro

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BC Hydro, the third largest electric utility in Canada, generates 43,000 to 54,000 GWh of energy annually for 94 percent of British Columbia's 4.4 million people. A complex system of 30 hydroelectric facilities situated throughout the province produces 90 percent of this energy. The watersheds supplying water to these plants range from small, rainfall-dominated mountain-coastal hydrologic environments to large interior drainages supplied with warm-season snowmelt, glacier-melt and convective rainfall. This hydrologic system contributes flows to three of the largest river systems in North America, namely the Fraser, the Columbia, and the Peace-Mackenzie. The complex topography and highly variable weather of this Pacific coastal province pose extreme challenges to BC Hydro meteorologists producing weather forecasts that drive reservoir-specific inflow forecast models. BC Hydro meteorologists employ short-term numerical weather prediction forecasts from a high-resolution multi-model ensemble of mesoscale models run operationally at the University of British Columbia Geophysical Disaster Computational Fluid Dynamics Centre in Vancouver. For medium-range weather, specific forecasts from the 42-member North American Ensemble Forecast System are extracted to produce probabilistic scenarios. In addition our forecasters must predict temperature-driven electrical system load and evaluate short-term severe weather risk. We are evaluating and adjusting these forecast methodologies. We are exploring new avenues of research such as gene expression programming to improve forecasts. Ultimately our goal is a forecast system starting with numerical weather models driving hydrologic-reservoir or other engineering models, which in turn drives economic, social, and environmental decision-making models in a complete end-to-end forecast system.

2. Predictive Uncertainty in Flood Forecasting

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This work aims at discussing the use of "predictive uncertainty" in flood forecasting and water resources management, particularly when meteorological ensemble forecasts are available.
Using data from actual operational flood forecasting systems, this work shows the improved expected benefits that can be obtained by fully incorporating predictive uncertainty into the decision making process, instead of using deterministic forecasts (as presently done) or by simply delivering to the end user uncertain, and hardly understood, forecasts (as commonly planned to be done).
This work also introduces and discusses the presently available continuous (Hydrologic Uncertainty Processor, Bayesian Model Averaging, Model Conditional Processor, etc.) and binary (Logistic Regression, Binary Multivariate Bayesian Processor, etc.) uncertainty processors, showing their performances on the basis of actual data derived from operational flood forecasting systems.
Finally, the problem of incorporating meteorological ensembles into hydrological predictive uncertainty is discussed and a number of possible alternatives is presented setting into evidence the problems that currently limit their use. The main problems for proficiently use meteorological ensembles relate to (1) the lack of long forecasting meteorological runs for which precipitation forecasts have been saved as opposed to the presently available re-analyses; (2) the continuous improvements in the meteorological models that modify in time their performances combined to the lack of willingness of the meteorological centres of re-running the new versions on past data; and (3) the difficulty at tagging the different members of the ensembles .

3. Rainfall and runoff ensembles produced based on the quality index of radar precipitation data

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The aim is to present results of rainfall ensemble generation from radar-based data and using them to produce runoff ensembles. The rainfall ensembles are generated based on information about radar data uncertainty, which is introduced as quality index fields. The used scheme of the quality index is based on selected quality parameters, that are connected with basic sources of radar errors and the radar data properties, among others. The quality information is attached to each radar data field and are employed to get the data error fields. Cholesky decomposition of the error covariance matrix is used to generate different perturbation fields that are introduced into the radar data. In this way various equiprobable rainfall scenarios as ensembles are generated on data from Polish weather radar network POLRAD and from the German Weather Service Essen radar. The runoff ensembles were obtained from the precipitation scenarios employing a rainfall-runoff model, that is a physical y-based, spatially distributed NASIM model. The investigations are carried out on two small catchments where flash floods constitute significant source of flood hazard: the mountainous upper Wisla river catchment and a semi-urban creek catchment in the Wupperverband area.

4. An overview of the use of reforecasts for precipitation forecast calibration

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The US NWS currently plans to calibrate their ensemble output through a stepwise procedure, first bias-correcting the forecast at the coarse resolution of the ensemble forecasts, then downscaling to a high-resolution reanalysis, followed (perhaps) by further post-processing to alleviate spread deficiencies.

This talk will present results of a critical examination of this approach to ensemble statistical post-processing, examining how well it works, comparing it to other standard statistical post-processing approaches, and coming to a recommendation as to whether this is a wise course of action for the US NWS, and if not, what other method or methods are preferable for ensemble post-processing.

5. Quantification and propagation of three sources of uncertainties in operational flood forecasting chains in mountainous areas

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Operational flood forecasting is a very important task in order to early detect potentially hazardous extreme rainfall-runoff. Such tasks are particularly challenging in mountainous areas, where the orography strongly complicates the setup and operational workflow of most components of an end-to-end flood forecasting system.
Each component of the system is affected by uncertainties linked to the orography, to the parameterization schemes of the models involved and the limitations of the observing platforms providing data in real time. A series of experiments in the Verzasca river basin (186 km2) focused on the propagation of different sources of uncertainty in flood forecasting were run during MAP DPHASE and in the framework of the COST Action 731.
For different events it was possible to quantify the predictive uncertainty yielded by inputs from ensemble numerical weather prediction models (COSMO-LEPS), the uncertainty in real time assimilation of quantitative precipitation estimations from a ensemble rain radar product (REAL) and the parameter uncertainty of the hydrological model adopted (PREVAH).
A first experiment propagating REAL (25 ensemble members) through the hydrological model (26 parameter sets) will be presented. This propagation generates 650 different initial conditions for forecasting with COSMO-LEPS (16 members). For selected events it was possible to generate a “superensemble” with 10400 members, accounting explicitly for 3 sources of uncertainty in the forecasting chain. This provides information on the uncertainty arising from having different initial conditions for hydrological forecasting.
Results based on the analysis of selected events with high peak-runoff show that the hydrological model uncertainty is less pronounced that the uncertainty obtained by propagating rain radar fields and COSMO-LEPS forecasts through the hydrological model.

6. A “Peak-Flow Box” for Supporting Interpretation and Verification of Operational Ensemble Flood Forecasts

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The development and implementation of new operational flood forecasting system basing on atmospheric ensemble prediction systems is a very actual topic in hydrological and meteorological sciences. Above all, two large international initiatives, HEPEX and MAP D-PHASE gave and are still giving a big impulse to the research efforts of both hydrological and meteorological communities.

Uncertainty analysis and communication are aspects that are obtaining more and more attention in hydrological sciences. First guidelines and tools for communicating uncertainty to end-users are in development.

Another field with need of new methodologies is the hydrology-related verification of simulations with hydrological ensemble prediction systems. Currently hydrologists still use methodologies that are established in atmospheric sciences.

In the framework of MAP D-PHASE we run a quasi-operational hydrological ensemble prediction system. A major goal of the our effort during MAP D-PHASE was setting up an end-to-end flood forecasting system and to investigate the propagation of uncertainty between a atmospheric and hydrological ensemble prediction system in real-time and for different basins. The setup operates without interruption since April 2007.

The interpretation of ensemble forecasts is challenging for both flood-forecasters and end-users. Intuitively the major-problem is the identification of the timing and peak-discharge of the peak-flow in the ensemble forecast. Thus, the core of this paper is the presentation of a pragmatic visual solution which is intended providing support for improved interpretation of ensemble flood forecasts. At the same time we aim to set the novel basis for hydrology-related verification of ensemble flood forecasts. This contributes to three of the main scientific issues listed by Schaake et al. (2007) in their overview paper on HEPEX: a) “Users Issues”; b) “Hydrological Forecast Verification”, and c) “Hydrological product generation”.

The approach has been called “Peak-Flow Box”. Related tailored metrics for the estimation of uncertainty and the quantification of agreement between ensemble forecast and observed hydrograph are introduced and discussed.

7. Evaluation and bias correction of daily QPF's : Impact on hydrological ensemble forecasts

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Flood forecasting over quick responding catchments such as Mediterranean ones requires precipitation forecasts to anticipate as far as possible significant rainfall-runoff events. These meteorological forecasts as such must be pre-processed before being used as inputs into hydrological models in order to satisfy their own constraints. Indeed, their quality is critical for a good discharge prediction: flood forecasters expect reliable and unbiased precipitation predictions.

We will focus here on the evaluation of daily Probabilistic Quantitative Precipitation Forecasts (PQPFs) taken from two different sources:
- the Ensemble Prediction System (EPS) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). These are currently operationally produced every day at 00hUTC and 12hUTC over a grid with a resolution of 0.45°.
- a probabilistic adaptation of meteorological model outputs based on an analog search for past situations similar to the expected one (ANALOG). These are also operationally issued for daily amounts at catchment scale. at 00hUTC

The distributions associated to these two PQPFs are evaluated in terms of accuracy and sharpness, by comparison with basin rainfall observations, with the continuous ranked probability score (CRPS - cf. Brown, 1974; Matheson and Winkler, 1976). Their operational performance is further verified using threshold scores (POD – probability of detection, FAR - false alarm rate, SPE - specificity). The target period is 2005-2007.

It appears that EPS are less spread than ANALOG, but more biased in terms of daily precipitation amount during rainy days. Concerning ANALOG, one external source of bias may come from the adapted operational meteorological model itself, while another one is internal and related to the length of the catchment-averaged precipitation archive. A statistically-based approach will be proposed for correcting this second term.

Finally, the effects of these biases and corrections will be evaluated on the end product: the hydrological ensemble forecast and illustrated by operational runs on a Mediterranean French catchment (Gardon at Anduze) for the flood event of 6 to 8th September 2005.

8. The comparison of the different inputs and outputs of hydrologic prediction system as: the full sets of Ensemble Prediction System (EPS), the reforecast and the calibration of this system by the verification tools of ensemble forecasts.

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The pre-operation European Flood Alerts System (EFAS) use Lisflood (a hydrologic distributed model) to provide medium-range flood simulations across Europe with a lead-time between 3 to 10 days and around 1141 observational stations. Such hydrologic prediction system relies on reliable and accurate input by ensemble predictions of Numerical Weather Predictions (NWPs) of the European Centre for Medium-range Weather Forecasts (ECMWF). The evaluation of EFAS by using the verification tools of ensemble forecasts in deriving Probabilistic Quantitative Hydrology Forecast is a challenge. So we concentrate to evaluate the medium range flood simulation on Danube drainage basin.
We use the verification tools of medium rang ensemble forecasts like: Continuous Rank Probability Score (CRPS), spread skill relationship, Relative Operating Characteristic (ROC) and Talagrand diagram to check the inputs of Lisflood as: full sets of EPS, the reforecast and the calibration of these full sets, to evaluate the Probabilistic Quantitative Hydrology Forecast on Danube drainage basin and to interpret the flood ensemble prediction system forecasts of this drainage basin.

9. Operational hydrological ensemble forecasts in Fra.nce. Recent development of the French Hydropower Company (EDF), taking into account rainfall and hydrological model uncertainties

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In operational conditions, the actual quality of meteorological and hydrological forecasts do not allow decision-making in a certain future. In this context, meteorological and hydrological ensemble forecasts allow a better representation of forecasts uncertainties. Compared to classical deterministic forecasts, ensemble forecasts improve the human expertise of hydrological forecasts, which is essential to synthesize available informations, coming from different meteorological and hydrological models and human experience.

In this paper, we present a hydrological ensemble forecasting system under development at EDF (French Hydropower Company). This forecasting system both takes into account rainfall forecasts uncertainties and hydrological model forecasts uncertainties. Hydrological forecasts were generated using the MORDOR model (Andreassian et al., 2006), developed at EDF and used on a daily basis in operational conditions on a hundred of watersheds. Two sources of rainfall forecasts were used : one is based on ECMWF forecasts, another is based on an analogues approach (Obled et al., 2002). Two methods of hydrological model forecasts uncertainty estimation were used : one is based on the use of equifinal parameter sets (Beven & Binley, 1992), the other is based on the statistical modelisation of the hydrological forecast empirical uncertainty (Montanari et al., 2004 ; Schaefli et al., 2007).

Daily operational hydrological 7-day ensemble forecasts during 2 years in 4 alpine watersheds were evaluated. Finally, we present a way to combine rainfall and hydrological model forecast uncertainties to achieve a good probabilistic calibration. Our results show that the combination of ECMWF and analogues-based rainfall forecasts allow a good probabilistic calibration of rainfall forecasts. They show also that the statistical modeling of the hydrological forecast empirical uncertainty has a better probabilistic calibration, than the equifinal parameter set approach.

10. On the importance of meteorological downscaling for short, medium and long-range hydrological ensemble prediction over France

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The SAFRAN-ISBA-MODCOU (SIM) distributed hydro-meteorological suite has been developed at Météo-France for several years. SIM is used for estimation of water resource and streamflow analysis on 881 gauging stations over France.

Three meteorological ensemble forecasts, with different time ranges, have been tested as input to the SIM suite. The first one is the ECMWF EPS, which is used at a 10-day range and a 1.5°-grid (51 members), in order to perform real-time medium-range streamflow forecasting with SIM. Then an ensemble streamflow prediction system (ESPS) using the Météo-France short-range PEARP EPS (60-hour range, 0.25°-grid, 11 members) was implemented. Finally, a seasonal ESPS forced by a DEMETER ensemble (2.5°-grid) of 9 members has been tested for 3-month forecasts.

The different methods for disaggregating meteorological ensemble forecasts downto the 8-km ISBA grid will be described. Statistical analysis of the skills of these systems (concerning both rainfall input and simulated streamflows) have been performed and showed the respective interests to the different approaches.

11. Impact of the use of two different hydrological models on scores of hydrological ensemble forecasts

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At operational flood forecasting centres, forecasters usually have to deal with forecasts issued by different models and combine them to support their decisions and communicate flood alerts to end-users. In this study a comparative analysis is conducted to assess the quality of streamflow forecasts issued by two different modelling conceptualizations of catchment response, both driven by the same weather ensemble prediction system. Weather forecasts come from the ensemble prediction system PEARP of Météo-France, which is based on the global spectral ARPEGE model zoomed over France. The model runs 11 perturbed members for a forecast range of 60 hours. The two hydrological modelling approaches used are: 1) the coupled physically-based hydro-meteorological model SAFRAN-ISBA-MODCOU developed at Météo-France and based on a fully distributed catchment model, and 2) the GRPE forecasting system developed at Cemagref and based on a lumped soil-moisture-accounting type rainfall-runoff
model. The study is conducted on a set of about 250 gauging stations representative of a wide range of upstream catchment areas and hydro-meteorological conditions in France. The discharges simulated by both systems are compared over an 18-month period (March 2005-September 2006). Skill scores are computed for the first two days of forecast range and the performance of both hydrologic ensemble forecasting systems is assessed.

13. High resolution ensemble forecast of flash-flood

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Several uncertainties damage the forecasts of Mediterranean intense weather events and propagates on hydrological response of the small rivers which are often affected by devastating flash-floods. Indeed, the nature and temporal and spatial scales of precipitating systems leading to flash flood, make difficult its forecast even for high-resolution convection-resolved numerical weather prediction systems.

Those meteorological uncertainties forecasting strongly influence hydrological modelling. During the last autumn, the ISBA-TOPMODEL hydrometeorological system, developed within the framework of the GMES/PREVIEW project, was used driven by meteorological forecasts from AROME. Hourly discharges at several outlets of the Cévennes-Vivarais (Massif Central) region were predicted every day. This hydrometeorological chain gives us the opportunity to evaluate the uncertainties of the high-resolution rainfall forecast and investigate their propagation in the hydrological model.

The uncertainty of the rainfall from the deterministic AROME forecast was first evaluated by comparison to observed rainfall (radar and raingauges). Then so as to take into account the uncertainties of the rainfall forecast and produce ensemble discharge forecast, we use the high-resolution ensemble AROME forecast rainfall fields as input to ISBA-TOPMODEL. Another method is investigated. Assuming conservation of some statistical or physical properties of the rainfall forecast some perturbations will be introduced in the AROME rainfall fields. In this way, we hope to take into account location errors, bias in the rainfall intensity distribution and bias in the areal rainfall at the hydrological scales. The two methods will be first carried out on the 21 and 22 October 2008 flash-flood events over the Cévennes-Vivarais region. The hydrological responses obtained with those two methods will be compared.

This study aims at preparing an ensemble flash flood forecast system that will be run during the observing periods of the HYMEX field experiment (http://www.cnrm.meteo.fr/hymex/).

14. Downscaling of seasonal forecasts for hydro-power

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A web portal for statistical downscaling was developped in the frame of the UE ENSEMBLES project. This portal has been used to downscale DEMETER and ENSEMBLES seasonal hindcasts of large scale predictors, to forecast local air temperature and precipitations on 9 stations near French dams. Direct estimates of river flow were also obtained with this tool, and will be compared to flow forecasts obtained using the downscaled T and P in a hydrological model. The goals are to evaluate the potential seasonal predictability of local variables necessary for hydro-power production forecasts, and the possibility to directly forecast river flows better than climatological estimates, without using a hydrological model.

15. An ensemble forecast approach for evaluating the convective-scale predictability of Mediterranean heavy precipitation

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This study considers the short-range kilometric scale forecasts of Mediterranean intense rainfall events and aims at assessing the three major sources of uncertainty for a limited-area model: the uncertainty on synoptic-scale and mesoscale initial conditions, the uncertainty on lateral boundary conditions and the modelling errors in the physical parameterizations and dynamics. For that purpose, methods of generation of ensembles are developed and used to quantify these uncertainty sources and identify the meteorological processes that govern convective-scale predictability of Mediterranean heavy precipitation events based on the fine-scale atmospheric model AROME.

The case studies are two past heavy rainfall events which occurred over Southern France: 21-22 Oct. 2008 and 1-2 Nov. 2008. The methodology here is first to use an appropriate selection of the members of the short-range large-scale ensemble ARPEGE forecasting system (PEARP) for these cases to take into account the uncertainty on synoptic-scale initial conditions and lateral boundary conditions. The uncertainty on mesoscale initial conditions is described through an ensemble of mesoscale data assimilation experiments. Regarding perfect synoptic-scale initial conditions and lateral boundary conditions, the assimilation of randomly perturbed observations (Monte-Carlo approach) permit to generate a set of initial conditions for the AROME model, using its 3D-Var data assimilation scheme. Both uncertainty sources are thus evaluated and their impacts on the fine-scale precipitation forecasts as well as on the mesoscale meteorological environments are also examined.

The observational phases of the HyMeX project (Hydrological cycle in Mediterranean Experiment) in 2011-2012 will constitute a test bed for evaluating the high-resolution ensemble forecasting methods developed in this study.

16. Ensembles forecasts for fast reacting watersheds

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Ensemble forecasts can be used to characterize the uncertainties of future developments of flood conditions. At least for internal use ensemble forecasts are more and more accepted by practitioners.
In this contribution the results of a first feasibility study are presented which was dedicated to the application of ensemble forecasts to identify flood-inducing precipitation in a low mountain range in South-East Germany. Starting with the specific needs of operational flood forecasts for fast reacting watersheds several meteorological ensemble forecast systems were tested: COSMO-LEPS, SRNWP-PEPS and COSMO-DE. These ensemble systems cover different spatial and temporal scales. With regard to flood forecasts the uncertainties of hydrological models, transferring the precipitation forecasts in runoff forecasts, were considered as well. Here a parameter ensemble approach was applied which is based on real-time runoff data. Similar developments in meteorological modeling would be useful.
Nevertheless the number of available hindcasts was very much limited; the main outcomes of our studies specify the future needs for intensified cooperation between meteorologists and hydrologists:

- At the moment the demand for ensemble forecasts of precipitation in low range mountains with regard to the specific needs of flood forecasts cannot be fulfilled in Germany.
- Additional work is needed to provide users with probabilistic assessments of single ensemble members. Different tools like Bayesian Model Averaging or Multiple Linear Regressions should be tested for their applicability with regard to specify these probabilities.
- The real-time utilization of measured data seems to be useful to update the probabilities of ensemble members.

17. ALADIN Limited Area Ensemble Forecasting

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ALADIN Limited Area Ensemble Forecasting (LAEF) has been developed at ZAMG within the ALADIN/LACE cooperation. It has run pre-operationally since March 2007. In the ALADIN-LAEF, several methods for dealing with the forecast uncertainties are developed, and implemented on ALADIN-LAEF for improving the forecast quality. Those are: 1) Perturbations to initial conditions are calculated by blending the large scale perturbation generated by ECMWF Singular Vector and the small scale perturbation generated by ALADIN-Breeding; 2) multi-physics scheme are applied for model perturbation; 3) NCSB (non-Cycling Surface Breeding) technique is for perturbations to initial surface conditions.
The performance of ALADIN-LAEF has been investigated, and the results will be shown at the meeting.

18. Statistical calibration of precipitation ensembles: an empirical comparison of a few methods

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At sites with measurements or accurate estimates of precipitation, it is often possible to enhance precipitation forecasts by means of statistical methods. In the first part, four statistical methods for calibration of single ensembles are presented and tested on data: (i) transformation of ensemble members such that they in the long run have the same climatology as the observations. (ii) as (i), but preceded by linear regression in order to take into account information about circulation pattern. (iii) use of scaling factors, essentially defined as the ratio of the weighted mean observed precipitation amount and the weighted mean model precipitation amount. (iv) the Bayesian Processor of Forecast (BPF). The first three methods all operate on each ensemble member individually, while the latter uses all members simultaneously and, thus, has better statistical foundation.

In the second part, several statistical approaches using multiple ensembles is investigated. The basic idea is to make simple BPF models, one for each ensemble or NWP system, and either combine these or choose the best one for each occasion. In the first method, linear regression is applied to predict the score of each BPF model which then are used to derive weights. In the second method, probabilistic neural nets are applied to predict the probability of each BPF model being the best one, and the probabilities are directly used as weights. In the third method, linear quantile regression is used to estimate the weights of all BPF models for certain quantile levels. Experiments show that combining several BPF models is slightly better than trying to pick the best one.

19. Hydrological Ensemble Prediction System for the River Scheldt and the Meuse Basins.

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A system based on the use of the SCHEME semi-distributed hydrological model and the ECMWF ensemble prediction system has been running pre-operationally since 2005 over two test catchments in Belgium: the Demer in the River Scheldt Basin and the Ourthe in the River Meuse Basin. The system delivers daily probabilistic streamflow forecasts for the next ten-day period. The procedure is now extended to the entire Scheldt and Meuse basins in Belgium and upstream in France.

Hindcasts from 2006 to 2008 have been performed, and a set of verification methods has been applied on the results, in order to evaluate the skill of the system for sub-basins with various sizes. The operational setup and future developments are outlined.

20. ECWMF: Supporting hydrological forecasting

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A combined medium-range and monthly forecasting system is now operational at the European Centre for Medium-Range Weather Forecasts. Previously, these two systems were run separately. The new combined system provides skilful predictions of small-scale, severe-weather events in the early forecast range, accurate large-scale forecast guidance up to day 15 twice a day, and large-scale guidance up to day 32 once a week. Additionally, the European Centre for Medium-Range Weather Forecasts (ECMWF) produces a reforecast dataset. Reforecasts are a large collection of forecasts for past dates produced with the most recent model version, so as to provide a sufficient number of training data and ensuring at the same time consistency between the training data set and operational forecast. It has been shown using reforecasts as training data can substantially improve error correction.
The presentation will discuss challenges and benefits of using reforecasts in the context of hydrological applications.

21. Radar Data Quality Index - A Tower of Babel ?

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A number of methods for quantifying the quality of radar rainfall measurements have been developed in recent years (e.g. Fornasiero et al., 2004; Friedrich et al., 2006; Helmert et al., 2008; Tabary, 2005; Szturc et al., 2007). These methods are producing a measure of quality for each radar pixel: the quality index (QI).

Different QI measures are producing different values for the same data, because the methods are based on different valid assumptions or they have been designed to serve different purposes.
QI measures can be used as the basis for the construction of radar measurement ensembles (Szturc et al., 2008), and they will produce different results as function of their way of construction.

Discussion:
Is the relatively large number of QI methods a wealth for the radar and meteorological community or does it increase confusion? Should there be recommendations, rules, guidelines to construct QI and ensembles or to use them, or would it merely be useful to start an intercomparison activity?

Hydrological users will not differentiate between ensembles produced by method A or method B: the results will be analysed as "the hydrological simulation based on ensembles".

22. MOGREPS Short-range Ensemble Forecasts of Precipitation

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The MOGREPS ensemble provides operational short-range ensemble forecasts over Europe with 24 members at 24km resolution (soon to be increased to around 18km resolution). MOGREPS is used by forecasters to assess confidence and uncertainty in forecasts, particularly in risks of severe weather including heavy rain events, and provides input to the Extreme Rainfall Alert service. MOGREPS has recently been enhanced by the addition of a site-specific processing system which provides improved site-specific extraction of forecasts, and also incorporates a Convective Diagnosis Procedure (CDP). The CDP provides enhanced diagnostics of convective shower risks, and allows inland advection of shower activity generated over the sea, thus improving the distribution of precipitation forecasts and the forecasts estimates of shower intensity. This presentation will provide an overview of MOGREPS capabilities for precipitation including some case studies of heavy rain forecasts and CDP enhancem ents. Some issues around post-processing of ensemble outputs for precipitation will also be discussed.

Precipitation forecasts for input to hydrological applications are strongly limited by the resolution of most ensemble models, including MOGREPS. Very high-resolution "convection-allowing" mesoscale models, with grid-lengths of order 1-3km offer the possibility of greatly enhanced resolution of precipitation systems including flash-flood generating severe convection, on length scales capable of resolving many smaller river catchments. However forecasts from such models are subject to large uncertainty from initial conditions and boundary forcing due to the very short life-cycles of precipitation systems, and should therefore be run in ensembles to provides reliable inputs to HEPEX ensembles. A convective-scale ensemble using a 1.5km grid-length model over the UK is being developed as a down-scaling of MOGREPS. Plans for this convective-scale ensemble will be described and latest progress reported.

23. A statistical methodology based on weather-typing that could potentially mitigate numerical model systematic biases for seasonal forecasts

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Forecasts of precipitation for long-range and seasonal periods are of limited ability. It is known that precipitation distribution are often linked to Weather Regimes. Recently, some studies (Chabot et al., 2008) have begun to examine whether the seasonal forecast of Weather Regimes could be usefully taken in account for operational seasonal forecasting.

Recently, an innovative statistical methodology has been developed to downscale climate simulations using a weather-typing approach (Boé and Terray, 2006). This new methodology is able to remove systematic numerical model biases while keeping seasonal cycle and variability.

It is thus proposed that this approach could be used in the context of seasonal precipitation forecasts to generate input to hydrological models.

24. Generation and Verification of Ensemble Precipitation Forecast from Single-Value QPF at the Catchment Scale

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It is widely recognized that, in some mean sense, the single-valued quantitative precipitation forecast (QPF), with value added by human forecasters at the NWS/NCEP/Hydrometeorological Prediction Center (HPC) and at the NWS/River Forecast Centers (RFC), is more accurate than the raw NWP single-valued QPF. It is also widely recognized that the current NWP ensemble forecasts tend to be under-spread and may not contain significant skill in the higher-order moments beyond the ensemble mean. For these reasons, the NWS Hydrology Program has been pursuing statistical techniques that can produce reliable precipitation ensemble forecasts from HPC/RFC's single-valued QPFs. In this presentation, we describe the improvements made since the initial development of the technique (Schaake et al. 2007). The improvements include explicit accounting of precipitation intermittency via the mixed-type bivariate meta-Gaussian model (Herr and Krzysztofowicz 2005), nonparametric modeling of marginal probability distributions, and parameter optimization under the Continuous Ranked Probability Score (CRPS), and other criteria. We present both dependent and independent validation results for selected river basins in the southern plains, California, and middle Atlantic regions, and comparative verification results with the operational GEFS precipitation ensemble forecasts.

25. Streamflow ensemble forecast driven by COSMO-LEPS for small-size catchments in northern Italy

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The quantitative precipitation forecast is a challenging task at the scales of interest for hydrological predictions over small and medium-size catchments. Although the use of high resolution limited-area models has improved the short-range prediction of locally intense events, an accurate forecast of the space-time evolution of these phenomena is still difficult, especially for ranges longer than 48 hours. Nowadays, in order to improve both the accuracy of hydrological model predictions and the reliability of uncertainty estimates, the use of meteorological ensemble systems as an input to river flow forecasts is increasing.
In the present study the usefulness and the skill of a Limited-area Ensemble Prediction System based on the non-hydrostatic limited-area model COSMO (COSMO-LEPS) is evaluated as a tool to drive a flood forecasting chain. The river hydrographs are simulated by means of the distributed rainfall-runoff model TOPKAPI.
The COSMO-LEPS methodology performs a dynamical downscaling of the ensemble forecasts produced by the global model of ECMWF. This methodology combines the advantages of a global-ensemble prediction system with the ability typical of limited area models to detail atmospheric phenomena on more local scales, particularly in those regions dominated by the effects of complex orography. COSMO-LEPS has been developed for the late-short to early-medium forecast range (48-132 h), and it has repeatedly been upgraded by increasing the layers in the vertical (from 32 to 40) and the number of members (from 5 to 16). The horizontal resolution is of about 10 km.
The performance of the proposed meteo-hydrological coupled system is evaluated for some small-size catchments located in the Emilia-Romagna Region, northern Italy. In particular, streamflow forecasts are simulated for the autumn and spring seasons in the years 2003-2007. Results have been investigated by statistical analyses, especially with respect to the verification of warnings and alarms.
Two typical responses result from the model coupling, depending on the atmospheric flow direction, localisation and orography of the selected catchments. Generally, in case of intense rainfall events leading to high discharge peaks, the forecast streamflows are underestimated when the flow is mainly from the south-west quadrant (downwind catchments), then the 75%-90% quantile confidence interval provides better results. On the other hand, the ensemble mean and the percentiles around the median provide better discharge forecasts when the flow is mainly from the east quadrant (upwind catchments).

26. Testing calibration techniques based on reforecasts for limited-area ensemble precipitation forecasts

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The project CONSENS (CONSolidation of COSMO ENSemble), developed within the framework of COSMO (COnsortium for Small-scale MOdeling), aims at consolidating the COSMO ensemble forecasting systems for the mesoscale. One of the purposes of this project is the implementation of a calibration technique to the ensemble precipitation forecasts.
Recent studies have recognised that a calibration for 24-h precipitation would be desirable to improve the forecast skill, especially for rare events, and have shown the potential of using reforecast to achieve this goal. Unfortunately, most of these works deal with lower resolution forecasting systems (based on global models), therefore, calibration of the precipitation forecasted at higher resolutions, as is typical of Limited Area Models, is still a challenge for the ensemble community. Hence, within the framework of CONSENS, a calibration strategy should be developed and tested, and then applied to the ensemble output.
The calibration of ensemble forecasts has been widely applied in recent years, introducing the use of reforecasts, namely dataset of prior forecast from the same model run operationally. In the present study, thirty years of reforecast of one member of COSMO-LEPS (the Limited-area Ensemble Prediction System based on the non-hydrostatic limited-area model COSMO), run by MeteoSwiss, have been used for testing the calibration strategy.
Three calibration techniques, which enable a calibration of the quantitative precipitation forecasts (QPFs), are considered: cumulative distribution function based corrections, linear regression and analogues (based on the similarity of forecast precipitation fields). This choice is due to the need to improve COSMO-LEPS QPFs especially as an input to hydrological models.
The impact of the application of these techniques to the ensemble precipitation forecasts operationally provided in the years 2003-2007 is here verified only over the Emilia-Romagna Region in northern Italy, due to the difficulty of collecting a large enough observation sample over the whole COSMO ensemble area.
First results are investigated by means of statistical scores, comparing the performance of the three calibration methodologies for different seasons, sub-areas, thresholds and forecast ranges. Tests have been carried out taking into account the sample stratification according to the forecast flow direction.
The dependence of the results on the spatial aggregation of model grid points over sub-areas has also been addressed.

27. Hydrological Ensemble Forecast for the River Danube focused on the applied downscaling method

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Hydrological ensemble forecast system is created at the National Hydrological Forecasting Service of Hungary (NHFS) for the upper and central Danube, with special emphasis on the Hungarian river reach. NOAA/NWS Global Forecast System (GFS) output 20-member ensemble system (20+3 members) and ECMWF EPS and VarEPS 50+3 member precipitation and 2-m-temperature products are routed through the NHFS hydrological modelling and forecasting system. Consequently the hydrological forecasting system produces 20 and 50-member hydrological ensembles. After application of a spatial interpolation (downscaling) method detailed in this paper, these ensembles enable the splitting of hydrological forecast errors into their components. One of those is the variability of the quantitative and spatial distribution of predicted precipitation values. The given variability can be estimated based on the statistics of the above mentioned 20 and 50 meteorological ensemble members. The impact of the current uncertainty of weather forecast on a given hydrological (water level or discharge) forecast can be numerically expressed by this applying the ensemble approach giving a major step forward relative to the earlier used statistical methods using past period forecast error characteristics.

28. Diurnal variation of summer precipitation in China

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Diurnal variations of summer precipitation over contiguous China are studied using hourly rain-gauge data from 588 stations during 1991 – 2004. It is found that summer precipitation over contiguous China has large diurnal variations with considerable regional features. Over southern inland China and north-eastern China summer precipitation peaks in the late afternoon, while over most of the Tibetan Plateau and its east periphery it peaks around midnight. The diurnal phase changes eastward along the Yangtze River Valley, with a midnight maximum in the upper valley, an early morning peak in the middle valley, and a late afternoon maximum in the lower valley. Summer precipitation over the region between the Yangtze and Yellow Rivers has two diurnal peaks: one in the early morning and another in the late afternoon.

29. An estimation of QPF uncertainty by ensemble skill

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Several convective storms, which occurred over the Czech territory and caused local flash flooding, were studied by using COSMO model in experimental mode. A driving COSMO (LLM) was run with the horizontal resolution of 11 km and with initial and boundary conditions derived from ECMWF analyses. The driven COSMO (SLM) used the horizontal resolution of 2.8 km and the initial and lateral data from LLM. The SLM integration started at 06 UTC and finished at 24 UTC of the same day. The storms produced the convective precipitation fields of various area extents and structures identified by radar. Multicellular storms with a repeated cell development over a given locality are the most common storm type in such situations. The time and space resolution of SLM enables a direct physical simulation of convective motions (convection permitting mode) and simulate realistic precipitation fields useful for hydrological modelling.

The events have been analyzed in an ensemble forecast regime. The ensemble of 13 members has been formed by linear shifting the initial fields in 8 directions. We have analyzed differences among the QPF of ensemble members by using traditional and fuzzy approaches. Specifically, we focused on the relationship between ensemble spread and ensemble skill. The spread and skill values have been calculated by using Fractions Skill Score. The ensemble skill has been evaluated by comparing the ensemble member forecasts with radar-based rainfalls and the spread was estimated comparing the ensemble member forecasts with the undisturbed control forecast. The effect of scale has been assessed by considering squares of various sizes that were centered in grid points of the verification domain. A scale dependence of spread and skill was analyzed at different times of integration and for various rainfall thresholds.

On the basis of good correlation between the FSS-spread and FSS-skill, we estimated the forecast FSS-skill for an independent event. We made an interpolation of spread-skill relation for four days and we made a projection of the fifth day ensemble mean spread into the interpolation curve. The skill forecast appears to be useful in uncertainty forecasting. It represents well the real skill and would be used as a combined input to the hydrological models together with deterministic or ensemble precipitation forecast.
The work is supported by the COST 731 (project OC112) and by the grant GACR 205/07/0905.

30. Reducing Meteorological and Hydrological Uncertainties in EPS : A Korean Case Study.

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This study compared pre- and post-processor methods that can reduce meteorological and hydrological uncertainties in ESP. In a pre-processor, the climate information was incorporated to adjust the values of meteorological scenarios or their probabilities while the hydrologic model errors were corrected in a post-processor. Three pre-processor methods and three post-processor methods were tested with a Korean case study where categorical and deterministic forecast information was incorporated into ESP that runs with the TANK hydrologic model. Simulation experiments using the observed data drew the following conclusions; (1) the use of the post-processor method considerably reduced the uncertainty of no-processor ESP than that of the pre-processor did, (2) the post-processor is more effective in the dry season than in the wet season, (3) some of the climate information and its use in the pre-processor were skillful during the wet season, and (4) the combination of the Schaake shuffle and the event bias correction methods as the pre- and post-processors could maximize the accuracy of the monthly ESP during the wet season, while the event bias correction method alone as the post-processor would be sufficient during the dry season because the hydrological uncertainty considerably dominates the meteorological uncertainty.

31. Probability forecast of intensive precipitation and floods in mesoscale catchments located in the Rhine basin – Experimental results and operational design.

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Forecasts of local surface variables like precipitation or discharge are uncertain. This arises from sources like the incomplete description of the state of the atmosphere and the hydrosphere and assumptions and simplifications made during the model development. To describe the forecast uncertainty ensemble prediction systems (EPS) are developed providing a number of realisations for the local-surface variable. In this presentation we propose an al-ternative forecasting technique based on a statistical downscaling which transfers the deterministic outcomes of a global numerical weather prediction model to the local scale. The statistical approach consists of two components: An analogue forecasting routine provides a probability forecast of daily areal precipitation for the basin of interest. Afterwards, a simulation model disaggregates the daily precipitation into spatiotemporal high-resolved realisations meeting the requirements of a distributed hydrological model. In the near future, the precipitation model will be tested as one component of the operational flood warning system running at the Environment State Agency Rhineland-Palatinate, Germany. It will provide a short-range forecast every six hours for several mesoscale catchments located in the German Rhine basin. In this presentation we will highlight the following points: I.) The precipitation model has been tested in a perfect prognosis environment with reanalysis data. A brief description of the precipitation model is given and the results of the model development are presented. II.) Operational flood forecasting requires a reasonable compromise between the ensemble size and the computing time needed to issue a flood warning. A basic concept is presented reducing the number of precipitation realisation without losing too much information to still provide a valuable flood forecast. The methodology is not only restricted to statistical downscaling techniques and can be transferred to EPS as well.

32. Inflow Forecast Verification at Hydro-Québec

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One way to assess the impact of meteorological forecasts on an hydrologic prediction system is to evaluate the quality of the inflow forecast. Here, we present the operational inflow forecast verification system that we developed at Hydro-Québec. The system is built primarily to verify ensemble forecasts, but also to evaluate the quality of deterministic forecasts. Our system is built around a number of different quality measures, as a variety of tools is necessary to do a thorough evaluation of a forecast's quality. We first describe our tools, then we explain how they are used to examine a series for forecasts, with some examples. The importance of having a measure that is close to the decision process, when applicable, is discussed. Finally, we present some results from the analysis of the impact of two different meteorological series on simulated inflows.

33. Verifying Hydrologic and Hydrometeorological Ensemble Forecasts in the U.S. National Weather Service

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Recent progress has been made in the NOAA/National Weather Service (NWS) on a comprehensive verification system for routine and systematic verification of hydrometeorological and hydrologic ensemble forecasts. The NWS Office of Hydrologic Development (OHD) has been developing an experimental hydrologic ensemble forecasting system to produce reliable hydrometeorological and hydrologic ensemble forecasts that account for atmospheric and hydrologic uncertainties. In order to verify the ensemble forecasting system, OHD has developed the Ensemble Verification System (EVS). In this paper, we present verification results for experimental precipitation and streamflow ensemble reforecasts derived for 14 days in the future from new ensemble preprocessing techniques. Flow ensemble forecasts were evaluated both against observed flows and against simulated flows (i.e., flows generated from observed hydrometeorological inputs) to separate the input and hydrologic uncertainties, assuming that uncertainties in the observed hydrometeorological inputs are much smaller than hydrologic uncertainty. Such verification analysis helps identify the different sources of uncertainty and skill across the river forecasting process, and evaluate the improvements in forecasting skill contributed by new science. OHD is also working closely with the NWS River Forecast Centers to define standard verification metrics and summary scores that could effectively help forecasters and end users in their decision making, as well as techniques for identifying historic analogs to real-time ensemble forecasts and bias-correcting ensemble forecasts in real-time (before the corresponding observations occur). We also describe the need for closer collaborations between the meteorological and hydrologic communities and the joint NOAA-Environment Canada project to evaluate and implement existing and emerging verification methods for atmospheric and hydrologic ensemble forecasts in the HEPEX Verification Test Bed.

34. Ensemble flood forecasting: a review

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Operational medium range flood forecasting systems are increasingly moving towards the adoption of ensembles of numerical weather predictions (NWP), known as Ensemble Prediction Systems (EPS), to drive their predictions. We review the scientific drivers of this shift towards such 'ensemble flood forecasting' and discuss several of the questions surrounding best practice in using EPS in flood forecasting systems. We also critique the main case studies in the literature that claim 'added value' of flood forecasts based on EPS and point to remaining key challenges in using EPS successfully.

35. An ensemble of hydrological climate scenarios

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Modelling of past, present and future climate is to an increasing degree involving simulation and evaluation of scenario ensembles. These ensembles encompass a range of different scenario characteristics, each of which adds uncertainty to the simulation. The most important characteristics that are currently considered are type of SRES emission scenario, type of GCM, initialisation of the GCM and type of RCM.

At SMHI, a large ensemble of climate model scenarios is being generated and subsequently used in hydrological simlulations of river discharge by the models HBV and HYPE. A bias correction procedure is applied to precipitation and temperature in the climate model results before they are used as input to the models. The climate model data acquisition, bias correction and hydrological simulations are combined in a semi-automatised system producing hydrological scenarios for different catchments in Sweden. For example, this system can process any of the climate model results currently being available through the ENSEMBLES project.

The hydrological scenario ensemble makes it possible to assess the total uncertainty as well as the contribution to it from each scenario characteristic mentioned above. In this study, we evaluate different aspects of the ensemble for a selected Swedish catchment by a split-sample approach, in which bias correction is calibrated for an early part of the historical reference period and then applied in hydrological simulations of the recent decades. Besides the uncertainty estimation itself, the approach opens up possibilities to rank scenarios with respect to their recent performance, both with and without bias correction, which may be relevant also for performance in a near-future perspective.

36. Cost-benefit analysis for operational water management with ensemble predictions

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One of the issues addressed in the Hydrological Ensemble Prediction Experiment (HEPEX) is the end-use of ensemble predictions in operational water management. When operational actions are taken on the basis of forecasts of events that are not yet measurable in the water system, the operations strategy is referred to as Anticipatory Water Management. A framework for implementing Anticipatory Water Management is presented that focuses on the use of ensemble verification methods and cost-benefit analysis with continuous simulation. Accuracy scores and skill scores can be used for bias analysis and correction, comparison of forecast products, and setting pre-alert or alarm decision rules on the basis of absolute requirements for hit- and false alarm rates. Accuracy and skill scores cannot be used to decide whether to apply Anticipatory Water Management if costs need to be evaluated. Using Cost/Loss ratios is not sufficient because, in operational water management, events are highly variable. Therefore, a dynamic cost function needs to be prepared. The total costs over a long period need to be estimated using continuous simulation of the water system and its operational water management strategy. Results of an optimised Anticipatory Water Management strategy are presented for a case study in the Netherlands

37. Tracking the uncertainty in flood alerts driven by grand ensemble weather predictions.

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One of the most important questions when using ensemble numerical weather forecasts for flood warning systems is how to best utilise this added information to improve forecasts and to avoid costly false alarms. The availability of global ensemble weather prediction systems through the 'THORPEX Interactive Grand Global Ensemble' (TIGGE) offers a new opportunity to develop these multi-ensemble flood forecasting systems. Here we present two case studies using the TIGGE database for flood warnings. The first catchment is the meso-scale Upper Severn catchment (4062 km2) located in the Midlands region of England. The second is the Upper Huai catchment (upstream of Wangjiaba, ca. 30672 km2), the sixth largest river in east-central China which connects to the Yangtse River. A coupled atmospheric-hydrologic-hydraulic cascade system driven by the TIGGE ensemble forecasts has been set-up for the both catchments. Two different hydrological models were used: LISFLOOD-RR for the Upper Severn and the Xinanjiang model for the Upper Huai. Probabilistic discharge and flood inundation forecasts were provided as the end product to study the potential benefits of using the TIGGE database. We assess the dominant uncertainties in the results and their propagation through the modelling chain. The spread of discharge forecasts is generally large and implies a significant level of uncertainty. Nevertheless, the results show the TIGGE database is a promising tool with which to forecast flooding

38. Performance and reliability of multimodel hydrological ensemble simulations: A case study based on 17 global models and 1061 French catchments

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Multimodel combination has been applied in several fields such as economy, statistics, psychology and meteorology, and results have been unanimous: combining multiple model outputs generally increases accuracy (Clemen 1989). In the hydrological science, studies concerned with model combinations have relied on different types of models and on various numbers of catchments and of methods (e.g. Shamseldin et al., 1997; Georgakakos et al., 2004; Ajami et al., 2006, Viney et al., 2009). The present study compares deterministic simulations of streamflow to simulation ensembles constructed from seventeen global hydrological models. The study exploits 1061 French daily streamflow time series extending over a ten-year period, of which five years are used for model calibration and five years are used for model and ensemble testing.

The probabilistic simulation performance, based on all 17 outputs, is first compared to the deterministic one, based on a combined model output where the combination method is the simple average. For all 1061 catchments, the Continuous Ranked probability Score of the probabilistic simulations is lower than the Mean Absolute Error of the deterministic simulations, indicating the superiority of the probabilistic performance. The reliability of the ensembles is next assessed using rank histograms and reliability diagrams. Results show that most ensembles are under-dispersed and would thus lead to overconfident decisions. Note that methods exist to calibrate such probabilistic distributions and some of them will be tested in a later phase of the study.

Further ensemble performance improvement is then sought through model selection. Subsets of the 17 global hydrological model outputs are created objectively using a genetic search algorithm to optimize the Continuous Ranked Probability Score. Results show that there exist many model subsets that improved the ensembles performance over the one obtained when pooling all 17 global model outputs.

39. Hydrometeorological Forecasts for Fast Reacting Catchments: Comparison of Quantitative Precipitation Forecasts and Impact Assessment on Streamflow Forecasts.

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Streamflow forecasts from quantitative precipitation estimates (observations) are possible on large catchments with acceptable anticipation. When smaller fast-reacting catchments are considered, the use of quantitative precipitation forecasts (QPF) becomes necessary and implies the production of hydro-meteorological forecasts. To answer to this demand, a way consists in developing a simple hydro-meteorological forecasting chain taking into account ensemble QPF or probabilistic QPF.

First, the following QPF will be assessed on a case of a significant and very recent event, the 1st November 2008 storm, producing flood on upper Loire river:
1) The “bulletin precipitation” (PB) provided by MeteoFrance (national meteorological supplier). They are produced twice a day (at 7hUT and 14hUTC), have a maximal horizon time of 48 to 60 hours and are given as ranges of values of daily amount of precipitation
2) The Ensemble Prediction System (EPS) provided by the European Centre for Medium-Range Weather Forecasts. They are produced every day at 00hUTC and 12hUTC over a grid with a resolution of 0.45°.
3) Probabilistic forecasts (ANALOG) based on an analog search for past situations similar to the expected one, forecasted by meteorological models (fields of pressure and humidity). These are produced for daily amounts at catchment scale and available at 06hUTC.

When dealing with quick flood or flash flood operational forecasting, two objectives can be distinguished:
1) Vigilance (some days before event) : good anticipation of rainfall event (appropriate anticipation : 3-7 days) and good event classification in terms of catchment reaction (no flood; low values ; usual; high values; exceptional)
2) Flood Forecasting (some hours before event) : good forecast of the peak value, the time to peak and the flood volume (for dam management for instance).

In this operational context, we will analyze benefits and drawbacks of our hydrometeorological forecasting system using these three QPF as inputs, for vigilance and flood forecasting. The impact will be illustrated by operational forecasts for the 1st November 2008 flood event of Loire river at Chadrac (1310 km²).

40. HEPEX Verification Test Bed

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For both atmospheric and hydrologic forecasts, forecast verification needs to be the driver in research and operations to help advance the understanding of predictability and help the diverse users better utilize the river forecasts. The goal of the HEPEX verification test bed is to evaluate existing and emerging verification methods for atmospheric and hydrological ensemble forecasts for hydrology and water resources applications, using forecast datasets from the HEPEX Great Lakes test bed. This verification test bed addresses the problem of improving the forecasting system, for which we need to evaluate the different sources of skill and uncertainty, and the problem of evaluating whether a forecasting system is useful, for which we need to know how a forecast is used to improve a decision-making process. This collaborative effort initiated by NOAA/NWS Office of Hydrologic Development, Iowa State University, Environment Canada, ECMWF, and Hydro-Québec will help to: identify key verification metrics and summary scores that could effectively help forecasters and end user in their decision making, as well as techniques for verifying real-time forecasts (before the corresponding observations occur) using historical analogs; propose methods that are appropriate for multivariate forecasts and methods to analyze forecast predictability on multiple space and time scales; define an optimal set of benchmarks to compute skill scores for hydrological forecasts; propose methods for verifying rare events and specifying sampling uncertainty of verifications scores; understand how to account for correlations in predictors and forcing variables; propose methods which take into account observational error (both measurement and representativeness errors). This project supports the joint collaboration objective between NOAA and Environment Canada to improve hydrologic forecasts. The final outcome of the test bed will be a documented set of algorithms and code for verifying atmospheric and hydrological ensemble forecasts for hydrology and water resources applications. Standard verification products will be proposed to effectively communicate verification information to modelers, forecasters, and end users. This will help improve collaborations between the meteorological and hydrological communities to advance forecast science based on rigorous verification.

43. Reconstruction of high-resolution rainfall series using multiplicative cascades.

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The reliable estimation of the frequency of extreme rainfalls over a surface at different accumulation periods is related both to the gage density within the area of interest and the availability of long rainfall series. However, these two conditions are rarely reached, especially dealing with infra-daily time steps. The scale invariance of rainfall fields offers a possibility to overcome such a limitation. The Universal Multifractal Model (Schertzer and Lovejoy, 1987) is a framework for analyzing the scale invariance of atmospheric processes. A network of over 200 daily raingages is analyzed at different accumulation periods, deriving 2 multifractal parameters and an intermittency-related one (Veneziano et Furcolo, 2005) for 4 climatic seasons. These parameters are used for implementing a multiplicative cascade. It allows to generate hourly rainfall series, assuming auto-affinity of point rainfall distributions at any temporal scale between 1h and 150 h.

Resulting rainfall series at locations of the daily raingage network have higher temporal resolutions. The temporal auto-correlation structure and the distribution moments follow scale-invariance. To assess the technique efficiency, the derived annual maxima are compared with the observed ones.
Results are discussed in terms of the impact of the misestimating of high rainfall rate location or value on the hydrological modeling of flash-flood events.

44. A nonparametric post-processor for removing biases from ensemble forecasts of hydrometeorological and hydrologic variables

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This paper describes a technique for quantifying and removing biases from ensemble forecasts of hydrometeorological and hydrologic variables. The technique makes no a priori assumptions about the distributional form of the variables, which is often unknown or difficult to model parametrically. The aim is to estimate the conditional cumulative distribution function (ccdf) of the observed variable given a (possibly biased) real-time ensemble forecast. This ccdf represents the 'true' probability distribution of the forecast variable, subject to sampling uncertainties. In the absence of a known distributional form, the ccdf should be estimated nonparametrically. It is noted that the probability of exceeding a threshold of the observed variable, such as flood stage, is equivalent to the expectation of an indicator variable defined for that threshold. The ccdf is then modeled through a linear combination of the indicator variables of the forecast ensemble members. The techni
que is based on Bayesian optimal linear estimation with indicator variables, and is analogous to indicator cokriging (ICK) in geostatistics. By developing linear estimators for the conditional expectation of the observed variable at many thresholds, ICK provides a discrete approximation of the full ccdf. Since ICK minimizes the conditional error variance of the indicator variable at each threshold, it effectively minimizes the Continuous Ranked Probability Score (CRPS) when infinitely many thresholds are employed. The technique is used to bias-correct precipitation ensemble forecasts from the NWS National Centers for Environmental Prediction (NCEP) Global Ensemble Forecast System (GEFS) and streamflow ensemble forecasts from the NWS River Forecast Centers (RFC). Split-sample validation results are presented for several attributes of forecast quality, including reliability and discrimination. In general, the forecast biases were substantially reduced following ICK. Overall, the technique shows significant potential for bias-correcting ensemble forecasts whose distributional form is unknown or nonparametric.

45. Atmospheric ensemble forecasts of precipitation with the convection permitting model COSMO-DE

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Quantitative information about precipitation is an essential input for hydrological predictions. For a lead time of more than several hours, precipitation forecasts are based on atmospheric models. The benefit of such forecasts for hydrological applications depends considerably on the ability of the model to resolve the relevant scales and processes.
Aiming to improve the very short-range forecast of severe weather triggered by deep moist convection and interaction with small-scale topography, DWD has developed the convection-permitting limited-area model COSMO-DE. This model has a horizontal grid-spacing of 2.8 km, covers the area of Germany and is in operational mode since April 2007. Major advances are the assimilation of radar observations and the formulation of a multi-component cloud microphysics scheme.
To properly take into account the limited predictability of processes on the small spatial scales, the DWD project COSMO-DE-EPS is developing an ensemble prediction system based on COSMO-DE.
Project activities comprise the generation, verification, statistical post-processing, and visualization of ensemble forecasts.
The ensemble perturbation strategy focuses on model physics, lateral boundary conditions, and initial conditions. Model physics is perturbed by altering distinct parameters of the physical parameterization schemes either individually or in combination. Lateral boundary conditions are perturbed by nesting the COSMO-DE-EPS members into members of the COSMO-SREPS (ARPA-SIM, Bologna) which itself is a nested EPS with a grid-spacing of 10km. The development of initial condition perturbations is in its early stages.
The quality of the current version of COSMO-DE-EPS is assessed by PACprove, a probabilistic verification tool developed as part of the project. The tool is able to calculate numerous probabilistic verification scores and also offers the option to focus on different spatial scales of the forecast.
We present the current status of ensemble development by showing results of our ensemble experiments.

46. Assessment of the total predictive uncertainty of a real-time hydro-meteorological flood forecasting system using bivariate meta-gaussian density

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Medium range rainfall forecasts are increasingly used in operational flood forecasting applications as they provide an inviting option for extending prediction lead-times. Nonetheless, there is significant uncertainty associated with hydro-meteorological simulations. As a matter of fact, techniques for assessing hydro-meteorological model uncertainty have received a great deal of attention by researchers in recent years. In any flood forecasting system, the predictive uncertainty originates from several causes interacting between each other, namely input uncertainty, model structure uncertainty and parameter uncertainty. Furthermore, it appears to be difficult to isolate the errors that stem from the individual model components.

In this framework, the study focuses on the analysis of the statistical properties of deterministic hydro-meteorological model error series, computed with respect to historic time series of observed discharge, in order to provide confidence intervals of discharge forecasts. Based on model error statistics, the proposed approach leads to the estimation of the uncertainty in an aggregated system (coupled atmospheric-hydrologic models), thereby rendering the assessment of uncertainty originating from the individual contributions unnecessary. Nevertheless, it is difficult to infer statistical properties from the prediction error since the residuals often appear to be non-stationary, in particular heteroscedastic, affected by serial correlation and with a non normal distribution. To solve this problem, the estimation of probability distributions of runoff simulation errors, conditioned by the value of flow, is performed using a meta-gaussian model. The latter is based on the appli
cation of a standard Normal Quantile Transform that makes the distribution of the model outputs and the model errors Gaussian in order to render straightforward the computation of confidence intervals.

The approach is tested by the means of a case study that focuses on a real-time flood forecasting system that was set-up on the Alzette River in Luxembourg. The integrated flood forecasting system uses the rainfall and temperature forecasts of the American atmospheric GFS model (deterministic run) as forcing data in a conceptual hydrological model (deterministic run) to predict river discharge. Confidence intervals of discharge forecasts are computed for various prediction lead times and compared with the respective observations of river discharge.

47. Using ensembles to represent rainfall uncertainties in radar QPE and QPF for hydrologic applications

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In the last years, new comprehension of the physics underlying the radar measurements as well as new technological advancements have allowed radar community to propose better algorithms and methodologies and significant advancements have been achieved in improving Quantitative Precipitation Estimates (QPE) and Quantitative Precipitation forecasting (QPF) by radar. Thus the study of the 2D uncertainties field associated to these estimates has become an important subject, specially to enhance the use of radar QPE and QPF in hydrological studies, as well as in providing a reference for satellite precipitations measurements.
In this context the use of radar-based rainfall ensembles (i.e. equiprobable rainfall field scenarios generated to be compatible with the observations/forecasts and with the inferred structure of the uncertainties) has been seen as an extremely interesting tool to represent their associated uncertainties.

The generation of such radar ensembles requires first the full characterization of the 3D field of associated uncertainties (2D spatial plus temporal), since rainfall estimates show an error structure highly correlated in space and time. A full methodology to deal with this kind of radar-based rainfall ensembles is presented. Given a rainfall event, the 2D uncertainty fields associated to the radar estimates are defined for every time step using a benchmark, or reference field, based on the best available estimate of the rainfall field. This benchmark is built using an advanced
non parametric interpolation of a dense raingauge network able to use the spatial structure provided by the radar observations, and is confined to the region in which this combination could be taken as a reference measurement (Velasco-Forero et al. 2008, doi:10.1016/j.advwatres.2008.10.004). Then the spatial and temporal structures of these uncertainty fields are characterized and a methodology to generate consistent multiple realisations of them is used to generate the radar-based rainfall ensembles scenarios. This methodology, based on the improvement of
the “String of Beads” model (Pegram and Clothier, 2001, doi:10.1016/S0022-1694(00)00373-5), is designed to preserve their main characteristics, such as anisotropy and the temporal variations of their spatial correlation.

The discussion of the results on a illustrative case study and their potential interest in hydrological applications will be also discussed .

48. Status of Hydrologic Ensemble Prediction at U.S. National Weather Service

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The U.S. National Weather Service (NWS) has been developing and using procedures for Ensemble Streamflow Prediction (ESP) since the late 1970’s. Initially, ESP was focused on long range prediction and on water supply forecasting in the western U.S where most of the Streamflow is generated by melting snow packs in late spring and early summer. Now our goal is to make use of atmospheric forecast information for time scales ranging from about 6 hours up to about 9 months to drive our hydrologic ensemble prediction models. This presentation will describe our management approach, the development of an eXperimental Ensemble Forecast System (XEFS) that will be implemented at 12 River Forecast Centers. It will include highlights of our experiences so far. And it will outline our view of the functional requirements for hydrologic ensemble prediction and some of the needs for development of improved procedures for using atmospheric forecast information for hydrologic ensemble prediction.

49. Precipitation Stochastic Modeling, Predictability and Forecasts

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We will first show that in a very general manner stochastic rainfall models point out very demanding ensemble size and resolution to get accurate estimates of rainfall predictability or dispersion. Furthermore, the latter cannot be safely assessed with only low order statistics.
Secondly, we will demonstrate that multifractal models give in a rather straigthfoward manner much more insights and information since the dispersion between two initially coinciding multifractal fields is also multifractal, but on a range of scale that is decreasing in time with a well defined scaling law. The relevance of this mechanism to a mesoscale meteorological model will be illustrated, depending on the availability of its outputs.
We conclude on the respective advantages of stochastic forecasts and ensemble deterministic forecasts, as well as on the prospects of their hybrids.

50. COST731 report on the use of radar quality information in Europe

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The Cost action 731 aims to characterise the propagation of uncertainty in advanced meteo-hydrological forecast systems. This includes the quality and uncertainty of meteorological observations from remote sensing and other potentially valuable instrumentation as well as their impacts on hydro-meteorological outputs from advanced forecasting systems.
In order to do so, COST 731 decided to compile the actual state of the use of radar products and quality information in the NWP community. A questionnaire was sent to the radar and the NWP community to request information on the availability and the actual use of radar quality information. Furthermore, the NWP community was asked to define their requirements on the observational data to feed this information back to the radar community. The results of this survey will be presented.

51. Monthly and seasonal EPS weather forecasts in hydrological forecasting in Finland

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Watershed Simulation and Forecasting System (WSFS) is used for flood forecasting and warning in Finland (www.environment.fi/waterforecast). ECMWF 10 days EPS weather forecasts have been used in the system operationally since year 2000. In the operational forecasts 10 days EPS is continued by climatology, to produce ensemble of 52 different hydrological forecasts. Since year 2007 ECMWF monthly EPS and since year 2008 seasonal EPS have been used in experimental forecasts which have been compared to forecasts based on climatology. Hydrological forecasts for periods of several weeks, even several months, can be valuable in some very large watersheds with big lakes and long delays, like Vuoksi watershed area in Finland. The inflow forecasts based on monthly and seasonal EPS were clearly better than the climatology based ones in southern and central Finland during exceptionally mild winters 2007-2008 and 2008-2009.

52. The COST 731 Action 'Propagation of Uncertainty in Advanced Meteo-hydrological Forecast Systems

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Hydrological risk management is putting an increasing demand on coupled, advanced hydro-meteorological forecasting chains. This research area is a subject of considerable current interest. The real-time forecasting of the targeted extreme events is a difficult task for many reasons, such as different modelling approaches for the atmosphere and hydrosphere, and the inherent. The COST 731 Action, launched in 2005, addresses the problem of forecasting (heavy) precipitation events and the corresponding hydrological processes in connection with the uncertainty inherent in this task. The main focus of the Action is the quantification of forecast uncertainty and its propagation through a meteo-hydrological forecast chain. COST 731 is structured in three working groups which deal with uncertainty cascading from observation (predominantly from radar) into numerical weather prediction (NWP) models, from observation and NWP into hydrological models, and the use of uncertainty as support in decision making. The groups of scientists involved in the Action therefore represent radar meteorology, NWP, hydrological modeling, as well as sociologists who deal with risk communication. MAP D-PHASE (Mesoscale Alpine Programme, Demonstration of Probabilistic Hydrological and Atmospheric Simulation of Flooding Events in the Alps), second WMO/WWRP Forecast Demonstration Project and constitutes an important element of COST 731.

In this presentation an overview of the COST 731 goals and a status of the current progress are given. A notable number of operational groups in hydrological modeling are in the process to implement and test probabilistic NWP input to produce probabilistic stream flow predictions. New developments include ensemble quantitative precipitation estimates with radar, including driving hydrological models with such input.

53. Calibration of Hydro-meteorological Ensemble Forecast at NCEP

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Experiments with coupled atmosphere-land surface–hydrologic streamflow model at NCEP suggest that there is potential for skill in ensemble streamflow forecasting. Systematic errors, however, pose a major limitation in skill. Work is underway to reduce the negative effects associated with systematic errors in hydrologic ensemble forecasting. Activities include representing model-related uncertainty with a stochastic perturbation scheme; combining the ensemble generated at NCEP with those produced at the Canadian Meteorological Center and at the Fleet Numerical Meteorology and Oceanography Center in the North American Ensemble Forecast System; employing an adaptive bias-correction scheme; statistically down-scaling ensemble forecasts to a fine scale mesh; generating a comprehensive fine scale observation-based precipitation analysis data set; and developing a technique based on the concept of "pseudo-precipitation" to facilitate statistical processing of non-continuous variables.

54. Downscaling large scale precipitation and temperature fields for hydrological seasonal forecasting and data assimilation

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Skillful seasonal hydrologic predictions are useful in managing water resources, preparing for droughts and their impacts, energy planning, and many other related sectors. Studies over the last two decades have demonstrated the feasibility of seasonal climate predictions with dynamical climate models. As these predictions become routinely available from several weather and climate prediction centers and research institutes such as NCEP, and the predictions have shown significant skill over the tropics and improved skill in the mid-latitudes, there is the expectation these predictions can contribute to the development of seasonal hydrologic prediction capabilities. However, one major challenge in using such prediction in seasonal hydrologic forecast is the disparity in spatial scales between those resolved in climate models and those needed for hydrologic applications. In this study, we develop new approaches to downscale the precipitation and temperature forecasts from the NCEP Climate Forecast System (CFS) for hydrologic forecasting. A Bayesian approach is used to merge CFS forecasts with observed climatology, such that the uncertainties related to the precipitation and temperature can be better quantified. Simultaneously, climate model forecasts are downscaled to an appropriate spatial scale for hydrologic predictions. When generating daily meteorological forcing, the system uses the rank structures of selected historical forcing records to ensure reasonable weather patterns in space and time.

To improve the initial condition for hydrologic forecasting, we implement a multiscale data assimilation system such that large-scale observations (e.g. remote sensing products) can be incorporated into the initial state of the hydrologic model. While traditional assimilation procedures suffer from an extremely high computational burden in large-scale applications, this multiscale assimilation system solves large problems very efficiently with controllable computational cost. The multiscale method tries to reproduce (or approximate) a high-dimensional signal with a series of low-dimensional signals at different scales, such that a large filtering problem can be broken down to a series of small filtering problems that are much easier to solve. The multiscale method also works in ensemble form (Monte Carlo samples), which is exactly how CFS provides its forecasts. We perform synthetic experiments with this multiscale assimilation system to study the potential benefit of integrating observational information for seasonal forecast.

55. Uncertainty assessment via Bayesian revision of ensemble streamflow predictions in the operational river Rhine forecasting system

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Ensemble streamflow forecasts obtained by using hydrological models with ensemble weather products are becoming more frequent in operational flow forecasting. The uncertainty of the ensemble forecast needs to be assessed for these products to become useful in forecasting operations. A comprehensive framework for Bayesian revision has been recently developed and applied to operational flood forecasting with deterministic weather forecasts. The Bayesian revision yields a posterior density, conditional on all information available to the forecaster at the onset of a forecast run. This conditional density objectively quantifies the uncertainty. Here the Bayesian approach is generalized for use with ensemble weather predictions. An end-to-end application of a Bayesian postprocessor for ensemble streamflow forecasts in the river Rhine forecasting system is presented. A verification of the postprocessor shows good performance when compared in terms of the ranked probability skill score to non-Bayesian uncertainty assessment, such as ranking threshold exceedance probabilities for members of a streamflow ensemble prediction. In this context it is also addressed how the proposed Bayesian processor can serve in supporting rational decision making for flood warning under conditions of uncertainty.

56. Multimodel Ensemble for Short Range Prediction (SREPS)

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The forecast of severe mesoscale events has a growing interest for the general public. Mesoscale models have already several problems to deal with such events because their predictability is very low even in the short-range. Precipitation has lower predictability than other meteorological parameters supplied by the numerical models. On the other hand, precipitation is the main input for the Hydrological models and then it is quite important to have better precipitation forecast in order to improve hydrological prediction models.

In such environment, probabilistic forecast may be a useful tool to improve the forecast of precipitation driving hydrological models to supply probabilistic predictions of discharge. Multi-model ensemble prediction systems are showing to be very useful to add value to mesoscale deterministic models. A multi-model ensemble prediction system (SREPS) focused on weather forecast up to 72 hours has been developed at the Spanish Meteorological Agency (AEMET). The system is running twice a day using 5 different limited area models (Hirlam, HRM, MM5, UM and COSMO) initialized with data from 5 different global deterministic models (ECMWF, GFS, GME, UM, CMC). SREPS has 25 members with around 25 Km resolution. The presentation will show the current status of the system and the verification of precipitation using a very high resolution network of European observations. We are performing as well one verification using data from the up scaling precipitation observations supplied by ECMWF. Comparison with the ECMWF EPS is also shown.

57. WMO research weather prediction activities relevant for ensemble hydrology forecasts

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This article will present several WMO/WWRP weather research activities that are relevant for developing of hydrologic prediction systems, including ensemble hydrological predictions.
THe Observing system Research and Predictability Experiment (THORPEX) of WMO is a key research component of the WMO disaster risk reduction activities and is focussed on extending the range of skilful forecasts of high impact weather up to 14 days ahead. Within THORPEX, the TIGGE component (THORPEX Interactive Grand Global Ensemble) aims, among others, to develop concepts for ensemble-based predictions of high-impact weather, including torrential rainfall. Therefore, there is a natural to link TIGGE and HEPEX, the later intending to demonstrate how to produce and utilize reliable hydrological ensemble forecasts based on atmospheric ensemble input.
There are two other WMO/WWRP projects of significance for hydrology predictions, which provide studying of deterministically predicted precipitation methods: one is the Convective and Orographically-induced Precipitation Study (COPS) established to further improve the quantitative forecasts of precipitation generated under orographic forcing. Another project is the Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region (MAP-D-Phase) that is addressing to use of the from limited-area ensemble forecasting and high-resolution atmospheric predictions in hydrological modelling.

58. MRED: Multi-RCM Ensemble Downscaling of global seasonal forecasts

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The Multi-Regional Climate Model Ensemble Downscaling (MRED) project addresses the question, Do regional climate models provide additional useful information for seasonal forecasts? Nested regional climate models (RCMs) have long been used to downscale global climate simulations. In contrast the use of RCMs in seasonal forecasting has received little attention. MRED is systematically testing the RCM downscaling methodology by using a large ensemble of downscaled global seasonal forecasts, produced by a suite of seven RCMs. The first stage will downscale historical winter forecasts from a T62L64 version of the U.S. National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS). A global seasonal forecast model based on the NASA Goddard Space Flight Center GEOS5 GCM, currently in development, also will be downscaled. The initial focus is on winter in order to evaluate snow cover, snow melt, and the usefulness of higher resolution for near-surface fields influenced by complex terrain.

The RCM ensemble covers the conterminous United States at approximately 32 km node spacing. Each RCM produces an ensemble of 15 members per year over a period of 22+ years (from 1982 to 2003+) for the forecast period 1 December – 30 April. Ensemble members are produced using a lagged ensemble approach; i.e., using output from global model runs that start from different dates in November before the forecast period. The total ensemble size will thus be (2 global models) x (7 RCMs) x (15 members per RCM) = 210 members. The RCMs provide hydrometeorological output in a standard netCDF-based format for a common analysis grid. MRED compares individual RCM and global forecasts as well as ensemble precipitation and temperature forecasts which are used to drive hydrological land surface models (LSMs). The project also evaluates wind, humidity, radiation, and turbulent heat fluxes, which are important for more advanced coupled macro-scale hydrologic models. Ensemble metrics such as spread, skill, and the resolution and reliability of categorical forecasts also will be evaluated. Process-oriented analysis will be performed to link improvements in downscaled forecast skill to regional forcing and physical mechanisms.

This presentation is dedicated to the memory of John Roads, who had the original vision for MRED and led its development into a funded multi-institution program. John passed away ten days before the start date of the project.

59. Communicating uncertainty information with warnings of natural hazards : COST731

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Some uncertainty information is usually generated when making forecasts of natural hazards, e.g. when ensemble methods are used. It is presumed that this is useful for the end user in deciding what actions to take and what warnings to issue. However, there is considerable debate about how much uncertainty information should be communicated and how best to present it to achieve a useful balance between providing an insufficient or unconvincing amount of information or causing a complete data overload. The overall goal must be to persuade the decision maker to believe in the risk, appreciate its urgency, motivate her or him to make the appropriate responses and empower him or her to explain those choices and motivate others involved in the disaster response chain. While it is clear from surveys that most end-users do wish to receive uncertainty information with hazard forecasts, it is less clear how the information should be presented and also how it is used by the end-user. This must also take account of how the uncertainty evolves dynamically, with the forecast, during the lead-in to the event. In particular, when communicating risk to the general public there are many sociological factors, including age and cultural background, which influence the success or failure of a warning approach.

Some of these topics were discussed at a COST731 special meeting in Dublin, Ireland in 2008. The meeting had presentations and demonstrations from a number of speakers actively involved in operational warning systems. This paper starts with a general review of the topic of communicating uncertainty, including sociological and psychological contributions to risk perception and then summarises the main issues and conclusions from the Dublin meeting, focussing on meteorological and hydrological hazards and including specific examples.

60. Object-oriented SAL Verification in Hydrological Catchments of Finland

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SAL (Structure-Amplitude-Location) is an object-based verification method suitable for the verification of QPF forecasts within specified domains like hydrological basins. SAL has been applied for several river catchments of various sizes by verifying deterministic forecasts originating from both global (ECMWF) and regional (HIRLAM_RCR, HIRLAM_MB71) models. QPF fields generated by human forecasters, utilizing grid-editing forecast production tools, are also verified to estimate the potential added value of human intervention to NWP. Radar-derived QPE fields are the main source of "observed truth" data but also and rain gauge data can be utilized. The size of the catchments varies between three to thirty thousand square kilometers. The results confirm that higher resolution models do, indeed, perform better than the coarser ones. SAL hence seems to exempt the notorious "double penalty" effects.

61. A combined approach for generating skilful forecasts of weather variable forcings for global streamflow forecasts

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Novel approaches to pre-process (calibrate) 2-m temperature and precipitation forecasts for hydrologic applications are explored using both ECMWF medium-range ensemble weather forecasts and the ensemble reforecast data set published by the NOAA Earth Systems Laboratory (Climate Analysis Branch). As in several previous studies, verification indicates that post-processing (calibrating) the ensemble may be necessary to provide meaningful probabilistic inputs for hydrologic applications, here focusing on forecasting streamflow of large international river basins. We apply a novel statistical correction approach by combining a selection of approaches used in the literature [e.g. logistic regression, and quantile regression] under the general framework of quantile regression to improve forecasts at specific probability intervals. Second, we also introduce climatological quantile probabilities in the model selection and calibration so that our approach ensures that the forecast probability distribution function represented by the ensembles has skill no worse than either a forecast of persistence or climatology. Third, we introduce a post-processing methodology for performing model selection that generates ensemble forecasts with an informative ensemble skill and spread relationship. To do this we conditionally select different historic scenarios for model development with similar atmospheric stability as the current state of interest. Finally, we examine the issue of spatial and temporal scale decomposition on calibration performance of the weather forcing skill and resultant streamflow forecasts. Results for a few selected river basins with different climatic regimes will be assessed using traditional (probabilistic) verification measures as well as a new measure we introduce that examines the utility of the ensemble spread as an estimator of forecast uncertainty.

62. Ensemble hydrological forecasting for flood management in the Brenta basin

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In view of flood control by reservoir regulation in the Brenta basin, in the Italian Alps, an accurate flood forecast is needed some days in advance. Within the MAP D-PHASE project an ensemble hydrological forecasting system was setup capable to predict runoff hydrographs at some dams and river gauges. The system proved to provide useful information for water authorities and civil protection. But for some flood events some false-alarm 'outliers' in the ensemble members of the COSMO-LEPS meteorological system, i.e. high flood forecasts predicting runoff peaks and volumes much higher that the observed ones. If water volumes would be released from reservoirs as a flood mitigation measure relevant economic losses would result. A combination of structural and non-structural measures would be needed for an efficient flood management in the Brenta basin.
The paper shows the effects produced in a set of preferred options if existing storage capacity use in association with a flood forecasting system is introduced.

63. Ensemble forecasting at Météo-France. Potential for the precipitation forecasts

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Since June 2004 a short-range ensemble prediction system (PEARP system) has been running operationally at Météo-France once a day at 18UTC. The ensemble (11 members) is initialized using 12h-singular vectors and more recently blending breeding techniques have been introduced. PEARP uses a coarser horizontal resolution (from 120 to 23km over Western Europe) than the deterministic operational spectral model ARPEGE (from 90 to 15 km).
Important upgrades of the PEARP system are planned during summer 2009 including a new initialization procedure that combines an ensemble of analyses and singular vectors perturbations in order to better represent the uncertainties in the initial conditions. Different physical parametrizations will be used in order to take into account the effect of uncertainties in the model formulation. The size of the ensemble will be increased (from 11 to ~35 members) as well as the grid resolution (from 25 km to ~15km over western Europe), while keeping the spectral resolution nearly constant : the specific geometrical grid transformation of ARPEGE will be used. The new PEARP system will have the same characteristics as most of the existing global EPS but with a grid resolution over Europe close to most of the existing LAMEPS. Using the TIGGE data-base archive, the new PEARP system will be compared with other operational EPS. Particular attention will be paid to the short range probabilistic forecast of precipitation and, finally, the early warning of extreme events will be addressed.

64. Multi-sources QPE re-analyses and their introduction in hydrological models: elaboration of an informative database for hydrologic and climatologic studies and a powerful tool for hydrological ensemble predictions.

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To the hydrologist, radar technology should provide both a mean to follow the spatial dynamics of rainfall fields and a quantitative evaluation of precipitation depths. Combined together, this information would provide spatially distributed rainfall depths that are potentially more informative than traditional ground rain gauge networks that only give point rainfall estimate. Over the last years, many studies have focused on the assessment of radar-based precipitation data for simulating stream flows through a hydrological model. However, the continuous and rapid evolution of radar technology has made the assessment of the operational value of radar rainfall estimates very difficult. Moreover, most studies have dealt only with a limited number of 'selected' events on a limited number of « selected » areas.

In that context, Météo France (the French national weather service), in close relationship with several French hydrology labs, has decided to launch a national collaborative project aiming at producing a 10-year reference database of Quantitative Precipitation Estimations (QPE). The objective is to make use optimally at any time of all available information (radars, hourly and daily rain gauges, satellite data, model freezing level heights, ...) to obtain the best surface precipitation estimation. Subsequently, the goal is to make the resulting data base, consisting of hourly (possibly infra-hourly : 5 or 15 minutes), 1km2 both QPE and associated estimation uncertainties, covering the entire French territory, a common reference for hydrologists, used for calibrating the model parameters, assessing the added value of input high space-time resolution in hydrological models,...

A possible very interesting application of this work (that means both the obtained QPE data-base (completed in real time, in the future) and the methodology to benefit of this high space-time resolution in operational hydrological models) will be its use for hydrological ensemble predictions. Indeed,

On large catchments, for forecast times, less or equal to catchment's response time, uncertainties associated with hourly (or infra-hourly), 1-km2 QPE can be used to produced probabilistic QPE and then probabilistic discharge forecasts;

On small catchments, various precipitation forecasts for short horizon times can be produced from radar data (advection of observed cells...) and used as input for hydrological models: hydrological ensemble prediction are then produced.

The multi-source QPE re-analysis requires automated process of radar data and combination of sources, in particular combination of radar data with available rain gauge network. Methodology for automated identification and treatment of radar measurement artefacts (ground clutter, partial beam blocking, clear air echoes, anthropogenic targets, bright band...) is being developed and tested. This methodology and the first results of its application will be presented here.

65 - The European Flood Alert System – a review

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The skill in weather prediction has steadily improved over the past years through higher resolution models, improved physics, remote sensing data and better data assimilation methods. The skill in predicting intense precipitation has, however, remained low and the skill barely increased over the past decade (Hamill et al., 2007). Therefore, the hydrological community is looking increasingly at the use of ensemble prediction systems (EPS) instead of single (deterministic) forecasts for flood warning times beyond 48 hours.

In 2003 the European Commission started the development of a European Flood Alert System (EFAS), following the devastating Elbe and Danube floods in 2002. EFAS aims to simulate hydrological processes in trans-national river basins, and to provide harmonized flood information across Europe. The European Flood Alert System (EFAS) is the first flood early warning system on European scale incorporating multiple EPS and deterministic weather forecasts pre-operationally.
Currently input data comes (a) from the European Centre for Medium-Range Weather Forecasts where both deterministic and EPS (51 members) are provided twice a day, (b) from the German Weather Service (DWD) where also twice a day both the deterministic GME and COSMO-EU are provided, and (c) from ARPA-SIM (IT) which provides the higher resolution EPS COSMO-LEPS (16 members) once a day.

Hydrological ensemble forecasting on European scale required the development of new methodologies before meaningful and reliable flood forecasts could be issued to the hydrological partner organisations. Having implemented the system in a pre-operational way, EFAS research now focuses on further exploration of the EPS stream flow information, their visualisation for different end user communities and their application in risk-based decision-making. It additionally provides a platform for further research on flash floods, droughts and climate change.

66 - Dynamical and Statistical Downscaling of Meteorological Forecasts

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Downscaling methods are used to derive information on spatial or temporal scales finer than those explicitly resolved in the results of a numerical model. Typically this numerical model is a global general circulation model (GCM) that for practical reasons cannot be executed at resolution fine enough to directly supply information on the scale of interest for an application. The downscaling problem thus can be conceptually viewed as the application of a transfer function to GCM output fields in order to provide finer-scale information. Downscaling methods are divided into two broad classes, dynamical and statistical (empirical), that reflect the nature of the transfer function that is used. Dynamical and statistical downscaling each have advantages and disadvantages relative to one another, and within each class there are numerous specific approaches. The presentation reviews some of the more common downscaling approaches and discusses their relative merits and challenges. Some current multi-institution projects using various approaches also are surveyed.