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BOOK OF ABSTRACTS

MMEFS Operational hydrologic ensemble forecasting at the Ohio River Forecast Center

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Abstract:

The Ohio River Forecast Center (OHRFC), with the Middle Atlantic RFC (MARFC), and Northeast RFC (NERFC) in the Eastern Region of the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), and Southeast RFC (SERFC) from the NOAA/NWS Southern Region, developed and implemented the Meteorological Model based Ensemble Forecast System (MMEFS) for routine real-time operations in January 2013. The MMEFS utilizes forecast ensemble precipitation and temperature fields from the NOAA/NWS National Centers for Environmental Prediction (NCEP) Global Ensemble Forecast System (GEFS) and Canadian Modeling System (CMS), which together form the North American Ensemble Forecast System (NAEFS), as hydrologic model forcings for the Deltares (The Netherlands) Flood Early Warning System (FEWS) based NWS Community Hydrologic Prediction System (CHPS). The MMEFS runs automatically, producing 7-day lead-time, hydrologic ensemble forecasts for all RFC forecast points at 6-hourly time steps. Similarly, ensemble precipitation and temperature fields from the NCEP Short-Range Ensemble Forecast (SREF) are also used to generate CHPS based hydrologic ensemble forecasts, but with 87-hour lead-times. CHPS based hydrologic ensemble forecasts are generated from each NCEP GEFS (2, 06 and 18 UTC), NAEFS (2, at 00 and 12 UTC), and SREF (4, at 03, 09, 15, and 21 UTC) model runs throughout the day. The MMEFS forecasts are made available in near real-time to the public via a GoogleMaps based webpage (http://www.erh.noaa.gov/mmefs/). Testing on an experimental basis, including direct feedback from federal, state, and local government agencies, was necessary before operational implementation. The knowledge gained during the experimental period lead to changes and needed improvements for the usability of the MMEFS by end-users. The webpage graphics include, streamflow/stage ensemble traces, precipitation, temperature, and snow-water equivalent ensemble traces, stage probability of exceedance graphic, as well as summary boxplots with 5%, 25%, 50%, 75%, and 95% exceedance limits. The hydrologic ensemble forecasts are generated from CHPS using the operational, deterministic FEWS workflows that include Sacramento Soil Moisture Accounting (SAC-SMA) rainfall-runoff modelling, SNOW-17 snow accumulation and ablation modelling, streamflow routing, and reservoir simulation modelling, using RES-SNGL and RES-J models. This paper discusses the MMEFS design, operations, examples of some significant events, and a discussion of verification results.

Keywords: Ensemble, model, operational, forecast, real-time, probabilistic, prediction

References:

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Brown, James D., Dong-Jun Seo, Jun Du, 2012: Verification of precipitation forecasts from NCEP's Short-Range Ensemble Forecast (SREF) system with reference to ensemble streamflow prediction using lumped hydrologic models. J. Hydrometeor, 13, 808–836.

Exploring how the question influences the decision on the basis of probabilistic forecasts

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Abstract:

Some of the current research activities in ensemble and probabilistic hydro-meteorological forecasting analyse which probabilistic information is required by decision makers and how it can be most effectively visualised. This work, in addition, analyses if decision making in flood early warning is also influenced by the way the decision problem is posed. For this purpose, the decision-making game "Do probabilistic forecasts lead to better decisions?" (Ramos et al, 2013) has been repeated and expanded with variations in the way questions are formulated. In the Ramos et al. 2013 game, decision makers had to decide whether or not to open a flood release gate, on the basis of flood forecasts, with and without uncertainty information. A conclusion of that game was that, in the absence of uncertainty information, decision makers are compelled towards a more risk-averse attitude. In order to explore to what extent the answers were driven by the way the questions were framed, in addition to the original experiment, a second variant was introduced where participants were asked to choose between a sure value (for either loosing or winning with a giving probability) and a gamble. This set-up is based on Kahneman and Tversky (1979). Results show that the way how the questions are posed plays an important role in decision making and that Prospect Theory provides promising concepts to further understand how this works.

Keywords: Probabilistic forecasts, ensemble forecasts, decision making, game, Prospect theory

References:

Kahneman, D., Tversky, A. 1979. Prospect Theory: An Analysis of Decision under Risk. Econometrica, Vol. 47, No. 2. (Mar., 1979), pp. 263-292.

Ramos, M. H., van Andel, S. J., Pappenberger, F. 2013. Do probabilistic forecasts lead to better decisions? Hydrol. Earth Syst. Sci., 17, pp. 2219-2232.

Creating an ensemble of flash flood guidance models to assess physical flash flood processes and model skill in the Ohio River Basin

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Abstract:

Weather Forecast Offices (WFO) issue flash flood warnings, watches, and advisories based primarily on Flash Flood Guidance (FFG) issued by River Forecast Centers (RFC). Unfortunately, a lack of understanding (by both hydrologists and meteorologists), little to no post-event analysis to verify FFG values, and in many cases settling with a single-value FFG technique can create distrust and confusion, for forecasters, in a potentially life-saving product. WFOs are looking at tools like Flash Flood Potential Index (FFPI), Precipitation Return Periods, and statistical threshold frequency techniques to augment FFG and potentially improve their flash flood forecasting skill. These tools seem popular because they can lessen the uncertainty in forecasting flash flood events—allowing forecasters to apply better judgment. While some FFG techniques may be inherently better on both practical and scientific grounds, this cannot be reasonably confirmed at the RFC scale. An idealized experiment would verify a proven high-resolution single-value FFG model at the watershed scale with frequent, spatially consistent point observations. In the real world, this is impossible for several practical reasons. As an alternative to proper FFG verification, we propose an ensemble approach to FFG that allows forecaster to see the daily FFG variability and apply their judgment in the forecast cycle. We established an operational environment to generate and compare multiple FFG models at once in an ensemble format. The Ohio River Forecast Center (OHRFC) configured two commonly used FFG techniques as well as an experimental technique within the Community Hydrologic Prediction Service – Flood Early Warning System (CHPS FEWS). In its simplest form, it is a gridded model using moisture states from the Hydrology Laboratory - Research Distributed Hydrologic Model (HL-RDHM) in combination with gridded threshold runoff (TRO) (Schmidt, Anderson, & Paul, 2007). The other commonly used technique is currently the OHRFC's operational FFG and it utilizes the basin-lumped Sacramento Soil Moisture Accounting Model (SAC-SMA) in combination with gridded threshold runoff. The experimental FFG technique, SIEOFG (Saturation/Infiltration Excess Overland Flow Guidance), uses HL-RDHM soil moisture at various Saturated Hydraulic Conductivity-capped soil depths in combination with gridded threshold runoff.

The OHRFC is in the process of setting up variations of the three methodologies described above. We will produce FFG models using a calibrated and uncalibrated HL-RDHM, gridded-constant, lumped-constant, or variable TRO, and gridded or lumped moisture states. The ensemble will contain roughly 27 members (though this number is an initial estimate). Once established, basic statistics will be calculated to analyze confidence and convergence/divergence in various meteorological conditions. Because some models are based on specific hydrologic principles, confidence under certain hydrologic and physiographic conditions can also be assessed. This ongoing analysis will lead to a better understanding of the limitations of each model, allow forecasters to see more than one single model in a real-time capacity, perhaps encourage WFO's and RFC's alike to better attempt verification, and provide the WFO with some measure of confidence that could make the difference in a flash flood warning, watch, or advisory.

Keywords: Flash Flood Guidance, HL-RDHM, Threshold Runoff, Verification, Convergence, Ensemble, Confidence

References:

Schmidt, J., Anderson, A., Paul, J. 2007. Spatially-Variable, Physically-Derived Flash Flood Guidance, 6B.2, pp 1-12.

Conditional weather resampling method for ensemble streamflow forecasting

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Abstract:

Ensemble Streamflow Prediction (ESP) is a commonly used method for water resources planning on the seasonal time scale. The ESP uses the current conditions of the hydrological system as a starting point for the forecast and climatological weather input. Expected deviations from the average climate are not taken into account in the standard ESP implementation. Here, a variation to the ESP method is proposed that generates additional ensemble traces from resampled historical weather data. The additional traces make it possible to select and condition the ensemble on climate mode information, without loss of ensemble resolution and associated degradation of forecast skill. This enables to incorporate information about El Niño phase or other climate modes into the seasonal forecast. The performance of the method is evaluated for three subbasins of the Columbia River over 55 years of hindcasts (forecasts in retrospect). An improvement in forecast skill is found for two out of three subbasins. For the third subbasin, the skill is equal to that of the original ESP method.

Keywords: Ensemble Streamflow Prediction, seasonal forecasting, El Niño, Columbia River

References:

Beckers, J.V.L., Weerts, A.H., Tijdeman, E., Welles, E. 2014. Conditional Weather Resampling Method for Ensemble Streamflow Forecasting. Submitted to Water Resources Research.

Forecast-guided stochastic scenarios of monthly streamflows to lead times of 9 months

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Abstract:

The availability of long range streamflow forecasts is highly valuable for water resources management, particularly for the driest inhabited continent, Australia. In Australia, the Bureau of Meteorology currently issues probabilistic forecasts of total streamflow volumes for the following three months at over 70 sites at the start of each month. Water agencies have welcomed this service. However, many agencies have expressed strong interest in having the forecasts extended to longer lead times and having the three month total volumes broken down into monthly volumes. At very long lead times when forecasts are no longer skilful, the water agencies are interested in stochastic scenarios, which can be used in conjunction with the skilful forecasts as inputs to water allocation models for planning and operations.

In this study, we describe a new system for generating forecast guided stochastic scenarios of monthly streamflows to long lead times for use by water agencies. The system first generates ensemble rainfall forecasts statistically using seasonal climate model predictions of rainfall and sea surface temperature as predictors. The rainfall forecasts are used to force a monthly water balance model, coupled with an error updating and uncertainty quantification algorithm, to produce ensemble monthly streamflow time series forecasts to long lead times.

We apply the system to three catchments in south eastern Australia and evaluate the performance of the forecasts. Test results on three alpine catchments in south east Australia show that the forecasts are skilful to lead times of at least 2 months, and up to 5 months, depending on time of year. At longer lead times, skill scores are close to zero as forecasts revert to historically observed frequency distributions. Forecast distributions are reliable at all lead times.

Keywords: Seasonal streamflow forecasting, Water management scenarios

A strategy to overcome adverse effects of autoregressive updating of streamflow predictions

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Abstract:

For ensemble streamflow forecasting applications, rainfall-runoff hydrological models are often augmented with updating procedures that correct streamflow predictions based on the latest available observations of streamflow and their departures from model simulations. The most popular approach uses autoregressive (AR) models that exploit the "memory" in hydrological model simulation errors. AR models may be applied to raw errors directly or to normalised errors. In this study, we demonstrate that AR models applied in either way can sometimes cause over-correction of predictions (Figure 1). In using an AR model applied to raw errors, the over-correction usually occurs when streamflow is rapidly receding. In applying an AR model to normalised errors, the over-correction usually occurs when streamflow is rapidly rising. Furthermore, when parameters of a hydrological model and an AR model are estimated jointly, the AR model applied to normalised errors sometimes degrades the stand-alone performance of the base hydrological model. This is not desirable for forecasting applications, as predictions should rely as much as possible on the base hydrological model, and updating should be applied only to correct minor errors. To overcome the adverse effects of the ordinary AR models, a restricted AR model applied to normalised errors is introduced. We show that the new model is reduces over-correction (Figure 1) and improves the performance of the base hydrological model considerably.

Keywords: Error updating, Streamflow forecasting, Autoregressive model

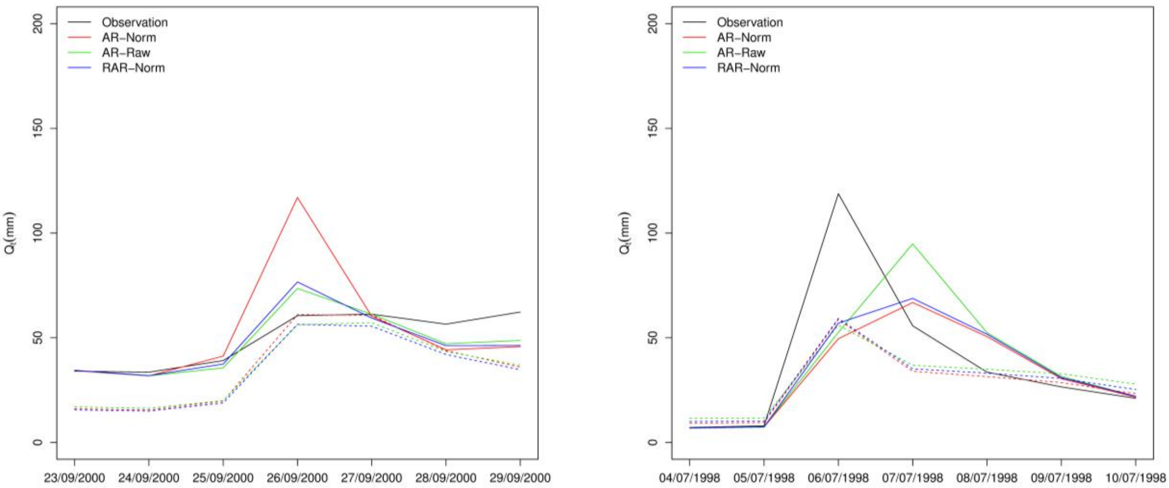

Figure 1: Examples of overcorrection with conventional autoregressive (AR) error models. Left panel shows overcorrection caused by an AR model applied to normalised errors (AR-Norm, red line). Right panel shows overcorrection by AR model applied to raw errors (AR-Raw, green line). (Dashed lines show predictions from hydrological models before error updating is applied.) In both panels, the restricted AR model developed for this study (applied to normalised errors – RAR-Norm, blue line) minimises overcorrection.

How not to ruin your whitewater kayak season*

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Abstract:

An increasing number of studies report the added value of ensemble forecasts over deterministic forecasts (e.g. Roulin, 2007; McCollor and Stull, 2008, Muluye, 2011; Kim et al., 2007). Most of these studies focus on hydropower production, reservoir management or flood protection. They are indeed vey important topics. There are, however, other potential users of streamflow forecasts. The use of streamflow forecasts by whitewater kayakers, rafters and canoers could provide a different insight on forecasts' value and eventually on how to communicate forecasts' uncertainty to the user. The typical kayaker uses the available precipitation and streamflow observations to decide on which river he should go paddling, mostly according to his or her level of skill. On some occasions, the decision is wrong. For instance, the water level can be too high for the kayaker's skill and the trip to the river is wasted. This small experiment takes place on three whitewater kayaking destinations in Saguenay-Lac-St-Jean (Quebec, Canada), namely Métabetchouane, Mistassibi and À Mars rivers. The latter is rarely rideable, but is a popular destination during spring melt.

The experiment also involves four fictive characters, who are kayakers with different level of experience (beginner, intermediate, advanced and expert). The value of different types of forecasts is compared through a cost-loss ratio framework based on the price of gas and on the distance between the city of Chicoutimi and each river. Depending on the streamflow, each river reaches a certain level and is suitable or not for each of the four kayakers. For instance, the beginner will chose to go out on À Mars River only if the flow is between 5 and 12m^3/s. Below 5 m^3/s it is not navigable and above 12m^3/s the rapids are to dangerous for his level of skill. Three types of streamflow informations are compared: Ensemble forecasts, deterministic forecasts and past observations. Streamflow forecasts are produced daily, with daily time step, for a three-day horizon. Ensemble forecasts are used to compute the probability associated to four streamflow intervals which correspond to the four kayakers' preferences. Forecasts' quality is assessed using the Ranked Probability Score (RPS), which is equivalent to the Mean Absolute Error for deterministic forecasts (Gneiting and Raftery, 2007).

Results show that for the one-day ahead horizon, streamflow observation for the previous day outperforms all forms of streamflow forecasts for Métabetchouane and Mistassibi. However, two-day and three-day ahead horizons, both deterministic end ensemble forecasts outperform the naive

forecasts (considering previous streamflow observations as forecasts). Ensemble forecasts also lead to better performances than deterministic forecasts according to the RPS/MAE comparison. As for forecasts value, ensemble forecasts lead to reduced losses, especially for the beginner kayaker.

* *The title is inspired by the title of a discussion thread on a kayak forum. People where basically complaining about the unavailability of streamflow forecasts*.

Keywords: *Forecasts' value, cost-loss ratio, decision-making, uncertainty.*

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A climate index weighting method for ensemble forecasts based on a bayesian resampling approach

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Abstract:

Climate state can be an important predictor of future hydrologic conditions. In ensemble streamflow forecasting, where historical weather inputs or streamflow observations are used to generate the ensemble, climate index weighting is one way to represent the influence of climate state. Using a climate index, each forecast variable member of the ensemble is selectively weighted to reflect the climate state at the time of the forecast. A new approach to climate index weighting of ensemble forecasts is presented. The method is based on a simple resampling approach for Bayesian updating. The original hydrologic ensemble members define a sample of the prior distribution; the relationship between the climate index the ensemble member forecast variable is used to estimate a likelihood function. Given an observation of the climate index at the time of the forecast, the estimated likelihood function is then used to assign weights to each ensemble member. The weights define the probability of each ensemble member outcome given the observed climate index. The weighted ensemble forecast is then used to estimate the posterior distribution of the forecast variable conditioned on the climate index. The Bayesian climate index weighting approach is easy to apply to hydrologic ensemble forecasts; its parameters do not require calibration with hindcasts, and it adapts to the strength of the relation between climate and the forecast variable, defaulting to equal weighting of ensemble members when no relationship exists. The method is illustrated with applications to ensemble streamflow forecasting systems, and the quality of the resulting forecasts are compared to those base on more traditional kernel climate index weighting. The results show that the quality of forecasts using the Bayesian climate index weighting to often better, even in cases where the kernel climate index weighting is optimized the verification measures that is compared.

Keywords: Ensemble streamflow forecasting; climate index; climate weighting; forecast verification

Operationalizing the Hydrologic Ensemble Forecast Service (HEFS) for internal forecaster guidance in both short-term flood forecasting and long-term water supply

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Abstract:

CNRFC forecasters have been incorporating output from the Hydrologic Ensemble Forecasting Service (HEFS) into routine operations over the past year. One challenge has been weighing the computation time of ensemble runs against timely forecast issuance. Another challenge has been the incorporation or exclusion of run-time modifications used in deterministic forecasting. Operational implementations will be presented.

One need cited for the development of hydrologic ensembles is the inclusion of forecast guidance on the short-term flood forecasting time scale.[1] Different iterations of display templates will be presented and analyzed for their advantages and disadvantages. One storm in February 2014 will serve as a case study of short-term probabilistic flood forecast displays.

With an historic drought occurring during 2013, much attention in California has been given to long-term water supply forecasts. Integration of the 16-day GEFS forecasts into water supply forecasting will be analyzed. Examples of displays of meteorologic and hydrologic uncertainty will be presented.

Keywords: Flood forecasting, probabilistic displays, HEFS, operations

References:

Demargne, Julie, et.al. 2013. The Science of NOAA's Operational Hydrologic Ensemble Forecast Service. Bulletin of the American Meteorological Society, Early Online Release.

Ensemble streamflow forecasting in large-scale tropical river basins in Brazil

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Abstract:

The use of hydrological streamflow predictions supports the decision making process in reservoirs operation, and can produce benefits by reducing damage from flooding, increasing dam safety and upgrading efficiency in power generation. These characteristics are highly desirable in Brazil, where hydropower provides about 70% to 80% of the country´s installed capacity, and where flood control is a relevant objective of reservoir operation. Recent studies show that ensemble forecasts permit the quantification of uncertainties associated with forecasts and can be very useful for reservoirs operation associated with flood control, but very few applications are found related to this theme in Brazil. However, a large number of global and regional meteorological models operationally run covering most of the country, and forecasts of those models are available for recent years. In the present case study, we show preliminary results of recently developed ensemble streamflow forecasts systems in two large-scale river basins in Brazil: the Tocantins and the São Francisco river basins. Streamflow forecasting needs in both rivers include flood forecasting and reservoir inflow volume forecasting. Reservoirs are used for power production, and their operation should not worsen natural occurring floods. Forecasts are obtained by running the large-scale hydrological model MGB-IPH with data from ground based rain gauges, rainfall data estimated using satellite sensors, and quantitative precipitation forecasts from numerical weather prediction models. In both river basins the operational forecasts are being changed from deterministic mode, based on single rainfall forecasts from CPTEC (the Brazilian Center for Weather Forecasting), to ensemble forecasts, based on a three day five member ensemble weather forecast of the regional Eta model run by CPTEC, and on 16 day forecasts provided by the Global Ensemble Forecasting System (GEF - NCEP-NOAA). We show hindcasting case studies in order to make a first assessment of the benefits of running ensemble streamflow forecasts. We show that rainfall forecast uncertainty is an important factor for streamflow forecast uncertainty, but in downstream reaches of the main rivers forecasting uncertainty is also related to not perfectly known upstream reservoir operations and poor quality of gauging observation.

Keywords: Tocantins, Brazil, São Francisco, ensemble, hydropower, inflow forecasting

Hydrologic ensembles for flash flood warnings at ungauged basins based on convection-permitting NWP forecasts

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Abstract:

Flash flooding events are typically triggered by extreme rainfall and efficient runoff production and are thus difficult to monitor and predict at the spatial and temporal scales of interest due to large meteorological and hydrologic uncertainties. To provide flash flood warnings for small ungauged basins, Météo-France and Irstea (formerly Cemagref) have developed a discharge-threshold flood warning system called AIGA, which combines the operational radar-gauge rainfall grids with a simplified distributed hydrologic model run every 15 minutes at a 1-km² resolution (Javelle et al. 2010). Operational since 2005 in the South of France, AIGA produces in real-time peak discharge estimates along the river network, which are compared to regionalized flood frequency estimates. Warnings are then provided to the French regional and national flood forecasting centers based on the range of the AIGA-estimated return period of ongoing events. The rainfall-runoff model is currently being enhanced to apply AIGA to the entire French territory by 2016.

To further extend the forecast lead time, deterministic rainfall forecasts from Météo-France's Application of Research to Operations at Mesoscale (AROME, Seity et al. 2010) convection-permitting model are ingested as time-lagged input ensembles in the hydrologic model. Operational since December 2008, AROME produces every six hours 30-h forecasts at a 2.5-km resolution to resolve deep convection processes. Deterministic AROME forecasts for the Meuse and Moselle river basins were provided for 20 significant rain events between January 2009 and December 2012. The time-lagged approach is a practical choice of accounting for the atmospheric forecast uncertainty when no extensive forecast archive is available for statistical modeling. It enabled us to produce AROME-based streamflow ensembles up to a 12-h forecast horizon and demonstrate the potential improvements in terms of flash flood event detection and effective lead-time. Warnings were also

derived by comparing AROME-timelagged precipitation forecasts with Flash Flood Guidance (FFG) values (Georgakakos 2006). Results for the 39 studied basins showed that the FFG approach, which does not account for the rainfall spatial and temporal distribution within the basin, did not degrade the quality of flash flood warnings.

Planned enhancements include ingesting the COSMO-DE-EPS convection-permitting rainfall ensembles (Gebhardt et al. 2011). Run operationally at the Deutscher Wetterdienst (DWD) since December 2010, the multi-model COSMO-DE produces 20 members at a 2.8-km resolution for a lead time of 21 hours on the North-eastern part of France. We also discuss how to assess other sources of hydrologic uncertainty, in particular the uncertainties from the parameters and initial conditions of the hydrologic model, and effectively communicate the uncertainty information for forecasters to better identify the location and severity of upcoming flash flood events.

Keywords: Flash flood, ungauged basin, convective precipitation uncertainty, time-lagged ensemble

References:

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Achievements, challenges and vision on ensemble forecasting at Quebec's government

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Abstract:

Hydrological forecasting is ongoing in Quebec since the 70s, mainly achieved by Hydro Quebec and Rio Tinto Alcan for hydroproduction optimisation purposes. Governmental Quebec's flood forecasting service was set up after the major 1996 Saguenay's flood. Since the late 90s, CEHQ has been forecasting for public dam management using Hydrotel (Fortin *et al*. 2001), a deterministic distributed model fed by a home based data management, transformation and diffusion platform called SPH (Turcotte *et al*. 2004). In 2011, major flooding occurred on the Richelieu river and authorities have decided that flood forecasting for public security purposes would be developed. It was decided that if forecast was to be issued, it would be disseminated with uncertainties bands. Although a sophisticated way to do it seemed ensemble forecasting, SPH, built in the early 2000 was not able to manage such a higher number of runs. CEHQ currently issues forecasts on over 50 catchments with the scope of increasing to over 100 by 2020. Two decisions came out of it, first we would first need to do uncertainties based on statistics of historical forecasts and our operational platform has to be updated. Currently on the process of changing this platform, we still face some challenges. Our distributed model takes a lot of computational time and thus 20 runs on one catchment seems to be the most we can do. Aiming for a 25 - 75 percentile range, the number of run needed for our wanted level of precision will have to be determined. We are interested in the short term prediction (day 1 – 3) so meteorological ensemble forecast may not be dispersed enough and we also ought to rely on initial condition uncertainties from model ensemble or Kalman ensemble filter for example. These challenges are addressed in partnership with Quebec's scientific community (Pietroniro *et al*. 2007; Velázquez *et al*. 2009; Abaza *et al*. 2013; Abaza *et al*. 2014)

Keywords: Operational hydrology; Uncertainties; Quebec flood watch; flood forecasting; distributed model

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Data fusion with gaussian processes: an approach to merging GEFS and CFS precipitation forecasts

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Abstract:

Informative flood and drought forecasts require skillful and accurate precipitation forecasts. A seamless time series of precipitation forecasts ranging from middle-term (14 days) to long-term (9 months) can facilitate hydrologic forecasting and decision making. In this research we use Gaussian Process Regression method to merge middle-term high-resolution GEFS forecast and long leading time CFS forecast. The prediction skill of the merged forecast is evaluated in Huaihe river basin in China. We also use a flood/drought sudden switch index (FD index) to indicate the threat of a large flood after a serious drought. The FD index is defined as the ratio of SPI (Standardized Precipitation Index) before and after the switching point. It is a simple and intuitive index that can be directly applied to middle and long term precipitation forecasting.

Keywords:

Precipitation forecast, Gaussian Process, Data fusion, GEFS, CFS, SPI

Hydrologic ensemble forecasts for decision makers: experimental applications in California and Nevada for hydropower management, water distribution, and flood risk management

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Abstract:

For the past couple of decades, the California Nevada River Forecast Center (CNRFC) has been producing Ensemble Streamflow Forecasts (ESP). These forecasts are generated by running the CNRFC's hydrologic model with current model states while imposing climatological "forcings" of temperature and precipitation to drive an ensemble of future hydrologic responses. The water resources communities in California and Nevada have become familiar with these forecasts. More recently, since 2011, hydrologic ensemble forecasts that incorporate short-term weather forecasts are being produced at the CNRFC. While these forecasts reduce the uncertainty in the near term from the climatological baseline ESP, it is challenging to explain the methodology behind them and to generate visualizations that are easy for users to absorb, especially with those unfamiliar with "classic" ESP. Early on, it was recognized that a good approach for expanding the utility of these new ESP forecasts is to deliver the forecasts in a raw format that users can input into their own modeling or processing system. The CNRFC is currently engaged with three different agencies that make decisions related to managing water resources. One agency is experimentally using ensemble forecasts in optimizing its hydropower operations, another in water distribution, and the third in flood risk management. In each case, the agencies receive CNRFC ensemble forecasts in two csv-formatted files each day. One file contains the first 14 forecast days with an hourly ordinate, while the second file contains 365 forecast days with a daily average ordinate. These agencies are able to run each ensemble member through their specific modeling or processing system and evaluate risks and opportunities within the context of their system. Engagement with these agencies on this level is accelerating the evolution of the Hydrologic Ensemble Forecasting System (HEFS) at the CNRFC as inconsistencies in the process of ESP generation are discovered and corrected, while the demand for information is driving development efforts aimed at improving the utility of these forecasts. This process also has other benefits in that CNRFC internal modeling structures are scrutinized at the basin level, leading to improvements in these structures, while data gaps get filled as these agencies make more of their data available to the CNRFC.

Conveying coherent flood forecast products from deterministic and ensemble forecast systems to users: challenges and opportunities at operational forecast centers

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Abstract:

The U.S. National Weather Service (NWS) California River Forecast Center (CNRFC) has been producing operational short-term ensemble streamflow predictions with the Hydrologic Ensemble Forecasting Service (HEFS) and the precursor eXperimental Ensemble Forecasting System (XEFS) since 2010. Developing representative and useful graphical and text summaries of such forecast information for sophisticated users has been challenging and dynamic. Of additional concern has been the provision of short-term ensemble guidance that is coherent with traditional deterministic flood forecasts. The addition of ensemble forecasts to the operational product suite has caused forecast users to reconsider notions of risk and certainty when making decisions based on forecast data.

One example cited is a project currently underway with the Eureka Weather Forecast Office (WFO) to prototype an interactive decision support service (DSS) for users of river forecasts for locations along the north coast of California. The work aims to develop an interactive graphical display that integrates both deterministic and probabilistic forecast information and allows users to customize the threshold level (stage), lead time and probability of exceedance at which to receive automated notification for a given river location. It is envisioned that such a service could complement or enhance existing operational flood warning notifications.

Keywords: Flood Forecasting, NWS, HEFS, XEFS, forecast displays, operations

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Preliminary results of the implementation of the hydrologic ensemble forecast system at the Arkansas-Red Basin River Forecast Center

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Abstract:

The Arkansas-Red Basin River Forecast Center (ABRFC) embarked on the implementation of the National Weather Service Hydrologic Ensemble Forecast System (HEFS) in October 2012 using the Community Hydrologic Prediction System (CHPS). The ABRFC plans to provide users with both short and long term probabilistic hydrologic forecasts. Emergency managers, reservoir managers, recreational users, and the informed public are targeted users of the short term forecasts. The targeted users of long term forecasts are primarily water managers and agricultural entities.

Probabilistic forecasts for most points in the ABRFC's area are produced daily. Graphical representations of these forecasts are created using the GraphGen software inside of CHPS. Products produced include probabilistic streamflow traces with their corresponding gage heights and exceedance probability plots for flow, volume and gage height.

Subjective analysis of this output was performed from primarily a user's perspective. This includes comparisons between HEFS output and output generated via a legacy pseudo-probability method used at the ABRFC. Future verification and analysis is planned to objectively validate these forecasts.

Keywords: NWS, HEFS, CHPS

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Fresch, M. 2013. Operational Implementation of the U.S. National Weather Service's Hydrologic Ensemble Forecast Service. 93rd American Meteorological Society Annual Meeting.

Research meets practice: the power lies in necessity

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Abstract:

The kick-off of our HEPS at WSL can probably be dated to summer 2005 when a severe flood event struck Switzerland, causing damage of more then 3 billion Swiss Francs. While many places experienced the worst flood damages ever, Zürich City stayed reasonably dry. However, the calculation of scenarios shifting the events centre of precipitation to the east showed, that Zürich was just very lucky not to experience severe damage. The damage potential of the City is set by the dense infrastructure of the City centre but the special feature in Zurich is the crossing of the Sihl River through Zürich main railway station. The riverbed is embraced by the ground level tracks and the underground tracks, limiting the through flow capacity to estimated 350 m^3/s. The final push for the efficient implementation of our system was then the construction of a new underground part of the railway station, which involved cutting down the through flow capacity by up to 60%. The coordination of the construction site and to maintain the safety of the workers a forecast system became essential. This was the beginning of a fruitful collaboration between research, public authorities and practitioners.

Our HEPS for the Sihl River is now operational since 2008. We provide 3 main forecast types whereof two are time lagged ensembles of deterministic models, with lead times of 24 and 72 hours which are updated 3 and 8 times a day. The main ensemble forecast is driven by the 16 members of COSMO-LEPS NWP, which has a lead time of 5 days. For better interpretation of this ensemble forecast we developed the peak-box (Zappa et al., 2013), which indicates the most probable magnitude and timing of a forecast event. Additionally the so called persistence table gives an overview of how the situation evolved over the past 5 days. Ensemble forecasts of precipitation, snow water equivalent and soil moisture are presented alongside. From spring to late fall our group provides also a weekend report for the authorities and 24h availability in case of critical situations.

In parallel to building up our HEPS the MAP D-Phase Project took place in 2007. Many research groups presented and tested their systems in operational mode, which were also evaluated by more than 40 end-users. Within this project our HEPS was set up for several Swiss basins, some of them are still operational. Thanks to MAP D-Phase the collaboration between our group and radar group of MeteoSwiss intensified. This gave us the opportunity to test new products like radar ensembles in operational flood and flash flood forecasting. In our contribution we will present our HEPS with focus on the Sihl River in Zurich (Switzerland) including a short review of a flood event. New products like radar ensemble nowcasts and short range radar ensemble forecasts can also be shown.

Keywords: operational flood forecasting

Reference:

Zappa, M., Fundel, F. and Jaun, S., 2013. A 'Peak-Box' approach for supporting interpretation and verification of operational ensemble peak-flow forecasts. Hydrological Processes, 27(1): 117-131.

HEPS challenges the wisdom of the crowds: the PEAK-Box Game. Try it yourself!

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Abstract:

In many situations the wisdom of the crowds (Galton, 1907) demonstrated to be superior to the estimation of single individuals. This is maybe one of the reasons why operational hydrometeorological services are more and more recognizing the added value given by ensemble prediction systems. A crowd of members has more wisdom than a single model output.

During our presentation, the crowd attending the session will be asked to estimate the outcome of a probabilistic prediction system and to perform better than the Peak-Box approach. The “Peak-Box” is a novel visual support that can be communicated alongside with ensemble discharge forecasts (Zappa et al., 2013). This visual solution should provide support in the assessment of actions relying on accurate estimation of peak-timings and peak-flows.

Keywords: flood forecasting, HEPS, user support, peak-box

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Using ensemble forecasts to minimize risk and support decision making under uncertainty in hydroelectric power operations

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Abstract:

Optimizing reservoir operations depends on the quality of the inflow forecasts, meaning that the better the forecast the less corrective action that needs to be taken once the actual inflows are realized. While the use of ensemble forecasts is becoming more widespread, the question still remains of what trace from the ensemble is the best one to use. The most common method is to use the ensemble mean with the assumption that the mean represents the best indication of the future conditions while containing information regarding the range of uncertainty within the ensemble. However, the uncertainty of concern from a reservoir operations point of view is not the uncertainty associated with the inflows but the impact of that uncertainty on reservoir operations. The risk to reservoir operations of using a particular forecast, whether it is a single trace from the ensemble or the ensemble average, is the cumulative effect over time of optimizing with one forecast and realizing a different future. The operational risk manifests itself as lost revenue, impacts to the environment, or reductions in operational flexibility that may limit water availability or flood control.

Here, we present a probabilistic risk-based method for selecting the optimal forecast that is designed to minimize operational risk. The central question being answered is 'given an ensemble of N forecasts, what is the risk of using trace J and realizing trace K?'. To do this, a set of N reservoir release schedules are calculated by optimizing reservoir releases for each trace. Then, each trace is systematically compared to every other trace by summing over the remaining N-1 traces, the consequence times the probability of realizing another trace. The consequence is defined as the difference in the operational objective of trace J and that of trace K while the probability is the probability of realizing trace K as compared to realizing trace J. This sum for each trace represents the probabilistic risk of assuming trace J and realizing trace K.

The approach is demonstrated using a hypothetical one reservoir, one river-reach system that is optimized to maximize revenue from energy production while also minimizing impacts to the downstream environment over a 6-month planning horizon. Downstream environmental impacts are calculated using an environmental score that considers minimizing the maximum daily water

temperatures as well as 6-hourly water level fluctuations. The consequence for each K-J pair is defined as the average of the difference in the normalized values of revenue and the environmental score. The results for this example show that the trace that minimizes risk is less than the ensemble mean in terms of the 6-month inflow volume and produces a 24-hour release volume that is 5% less than the optimal release volume calculated with the ensemble mean. The implications and consequences of these differences are also discussed.

Keywords: risk, probability, ensemble forecast, reservoir operations, optimization, uncertainty, decision support.

Seasonal hydrometeorological ensemble prediction system: forecast of irrigation potentials in Denmark

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Abstract:

The European Centre for Medium-Range Weather Forecast, Seasonal Ensemble Prediction System (ECMWF SEPS; Persson, 2011) of weather variables such as precipitation, temperature and evapotranspiration is used as inputs for a MIKE SHE integrated surface-subsurface hydrological model in order to generate probabilistic forecasts for irrigation potentials in the Ringkøbing Fjord area in Denmark. The main objective of the research is to evaluate the usability of the ensemble prediction system (EPS) and discuss the challenges and areas of opportunity when issuing forecasts generated with this methodology. Special attention will be given to the forecast of low flows due to the immediate effect these flows may have on the environment and on the groundwater availability for planning and issuing of groundwater extraction permits.

Due to the low resolution of the weather inputs, TL255 (~80 km), pre-processing of the data is made by means of downscaling techniques to obtain high-resolution input needed for the hydrological modelling. Moreover, bias-correction techniques are applied to the raw inputs to take into account the bias intrinsic in EPSs. Finally, forecast verification is carried out to give us a deeper insight of the strengths and weaknesses of the hydrometeorological prediction process. The quality of different characteristics of the forecast such as reliability, resolution and discrimination is assessed by means of several measures of validation. The measures are derived from the empirical joint distribution of the forecast and observed values (Murphy, et al., 1987, Jolliffe, et al., 2003).

Keywords: Seasonal EPS, Downscaling, Bias correction, Forecast Evaluation, Irrigation Forecast

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Ensemble streamflow prediction experience at Bonneville Power Administration

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Abstract:

Bonneville Power Administration is a federal non-profit agency within the Pacific Northwest. BPA markets wholesale electrical power from 31 federal hydro projects in the Columbia River Basin. The Columbia River rises in British Columbia and the drainage area encompasses 5 states before making its way to the Pacific Ocean. BPA works cooperatively with provincial entities, federal and state agencies and tribal members in managing the water resources under very complex hydrologic conditions. The Columbia Basin is subject to significant hydrologic variability in terms of seasonal volume and runoff shape between years. The region also suffers from being storage limited. As such, the snow pack is often used as additional reservoir storage, making adequately predicting the snow pack and when the freshet is likely to begin of utmost importance to the region. Part of managing the Columbia River involves balancing the often conflicting needs of users of the multi-purpose dams to adequately balance the competing needs of flood risk reduction, protection of endangered species, irrigation, navigation, recreation and power generation. Within BPA, the Power Generation Planning group has a team of meteorologists and hydrologists responsible for preparing both short-term and long-term weather and streamflow forecasts. The group uses the NWS Community Hydrologic Prediction System (CHPS) as its streamflow model and generates 14-day short-term natural flow forecasts during weekdays and provides long-term streamflow guidance using ESP to the end of the water year on a weekly basis. These bi-weekly studies are used in an operational hydraulic model that determines generation inventory while meeting the often conflicting constraints of the system. Because of the limited storage in the basin, seasonal water supply forecasts are used to determine how each of the projects is operated within the winter and early spring months. Projects must be drawn down to adequately attempt to capture the runoff during the snow melt season and therefore minimize flood risk, while ensuring that the project will refill completely making water available for irrigation, endangered species needs and adequate navigation during the dry summer and early fall months. One of the critical ancillary files provided includes forecasts of future water supply forecasts for each ensemble year and how the seasonal volume forecast might vary through each of those ensemble years. These "perturbed" seasonal volume forecasts are used to set constraints on the operations of the system.

Keywords: Ensembles, Risk, Reservoir Operations, Snowmelt, Power Generation

Developing climate-informed ensemble streamflow forecasts over the Colorado River Basin

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Abstract:

Home to arguably the most litigated river in the world, the Colorado River Basin provides water to over 30 million people and spans much of the American West, irrigating over 16,000 km^2 of land in the upper basin states of Wyoming, Utah, Colorado, New Mexico, and the lower basin states of California, Nevada, Arizona, and the country of Mexico. Managed by the United States Department of the Interior, Bureau of Reclamation (Reclamation), water resources over the Colorado River Basin not only provide water for municipal and agricultural use, but hydropower as well. Hydropower facilities in the basin have a generating capacity in excess of 4,200 megawatts [U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region, 2009]. Water stored within the Colorado River Basin is primarily the result of spring (April through July) snowmelt driven by accumulated winter snowpack throughout the Upper Colorado River Basin [e.g., Timilsena and Piechota, 2008]; numerous studies have indicated that the character of precipitation and snowmelt may change with anthropogenically-driven changes to the climate [e.g., Clow, 2010; Kalra and Ahmad, 2011; McCabe et al., 2007; Painter et al., 2010].

As the impacts of climate change are realized, the assumption of hydrometeorologic stationarity (i.e., the assumption that past hydrometeorologic conditions are statistically similar to future hydrolometeorolgic conditions) embedded within many hydrologic models is likely no longer valid over the Colorado River Basin [e.g., Brekke and Prairie, 2009; Milly et al., 2008]. As such, resource managers in the region, such as Reclamation, have begun to request increasingly more information to support decisions, specifically with regards to the incorporation of climate change information and operational risk. To this end, ensemble methodologies have become increasingly popular among the scientific and forecasting communities, and resource managers have begun to incorporate this information into decision support tools and operational models. Over the Colorado River Basin, reservoir operations are determined, in large part, by forecasts issued by the Colorado Basin River Forecast Center (CBRFC). Traditionally, the CBRFC produces both single value and ensemble forecasts for use by resource managers in their operational decision-making process. These ensemble forecasts are currently driven by a combination of daily updating model states used as initial conditions and weather forecasts plus historical meteorological information used to generate forecasts with the assumption that past hydroclimatological conditions are representative of future hydroclimatology.

Recent efforts have produced updated bias-corrected and spatially downscaled projections of future climate over the Colorado River Basin [Reclamation, 2013], of which previous iterations have been investigated [Miller et al., 2011]. In this study, the historical climatology typically used as input to the CBRFC forecast model is adjusted to represent future projections of climate based on data developed by the updated projections of future climate data. Ensemble streamflow forecasts reflecting the impacts of climate change are then developed. These forecasts are subsequently compared to non-informed ensemble streamflow forecasts to evaluate the changing range of streamflow forecasts and risk over the Colorado River Basin. Ensemble forecasts may be compared through the use of a reservoir operations planning model, providing resource managers with ensemble information regarding changing future water supply, availability, and reservoir management, ultimately aiding in the determination of possible implications for resource management. Further efforts could potentially combine the utility of hydrologic models with a dynamic evapotranspiration component to evaluate impacts due to changes in evapotranspiration rates or develop unique climate patterns with the use of a stochastic weather generator and weightings based on climatic teleconnections (e.g., El Niño Southern Oscillation).

Keywords: Climate, Ensemble, Streamflow, Bias-Corrected, Spatially-Downscaled, Colorado River Basin

Verification of water supply forecast tools in the Colorado River Basin: ensemble streamflow prediction and hydrologic ensemble forecast system

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Abstract:

Water supply forecasting has a lengthy history in the semi arid western United States where water is valuable and central to many aspects of the economy, the landscape, and life. As water demands increase and supply decreases, the demand for optimizing water management based on forecast informed decisions has increased the need for improved forecast services. This is particularly true for ensemble forecasts such as those examined and promoted by HEPEX. Historically, forecast agencies have largely relied on two forecast approaches: statistical models relating snow measurements and other predictor variables to runoff and simulation models, such as the National Weather Service River Forecast System (NWSRFS) (NWSRFS:NWS 2005),that to varying degrees account for physical processes and weather forecasts important in producing runoff. Forecasts from the NWSRFS are produced using the Ensemble Streamflow Prediction (ESP) technique (Day, 1985). As snow and land surface modeling capabilities and weather and climate forecasting have improved, the potential for applying these tools to realize forecast improvement has grown. In order to support leveraging these capabilities into water supply forecasting, we compare the skill and reliability of the three probabilistic forecast tools (two currently used and one in development) for seasonal water supply volumes in the upper Colorado River basin. We find the two current forecast tools are generally comparable in forecast skill and reliability except late in the forecast season when hydrologic ensembles from the simulation model fail to adequately capture the range of observed outcomes. However, we find that applying a statistical post adjustment technique largely addresses this deficiency in the ensembles output from ESP.

The current ESP ensembles are based on current hydrologic conditions and future precipitation and temperature forecasts derived from a combination of short term deterministic weather forecasts and historical time series. Because there is no long term archive of these forecasts and the weather forecast used in the ESP scheme, it is difficult to describe and quantify the sources of uncertainty of these ensembles. The National Weather Service has recently developed the Hydrologic Ensemble Forecast System (HEFS) which will enhance traditional ESP by incorporating reliable short, medium, and long range forecasts for both temperature and precipitation and a hydrologic post processor

(Demargne et al., 2013). These enhancements provide the ability to better quantity and communicate the uncertainty in the forecasts. We will evaluate HEFS as an additional water supply forecast tool by comparing the skill and reliability of HEFS to the current forecast tools. Preliminary results and previous studies (Werner et al., 2005) suggest that forecast skill will be comparable to the previous tools while the HEFS ensembles may be more skillful at certain times in the forecast season especially during the critical spring snowmelt and runoff season when temperature variability is most important. By validating the current and additional water supply forecasting tools, this study aims to inform management decisions regarding forecasting tools and techniques that may be required to fulfill the demand in future forecasts requirements in the Colorado River Basin.

Keywords: Verification, Ensemble, Water Supply, HEFS, Colorado River Basin

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Seamless forecasting of floods and droughts on a global scale

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Abstract:

Early warning systems of hydrological extreme events (e.g. floods and droughts) at the global scale are becoming increasingly important due to the combined threat of increasing population settlement in vulnerable areas, such as those prone to flooding or water shortage, and the possible risk of an increase of the intensity of extreme weather due to climate change. The recent availability of long-term global gridded datasets of precipitation and temperature alongside with improvements in skill of weather prediction provide a unique opportunity to invest in sectorial applications.

The European Weather Centre for Medium Range Weather Forecasts (ECMWF) is a recognised world leader organization in numerical weather prediction (NWP) and provides operational forecast products from the short-range (few days) up to the seasonal scale. In the last year ECMWF has been particularly active through EU research founded projects in demonstrating the capability of its forecasting system to drive impact modelling systems. This paper reviews the outcome of this effort by assessing the performance of the new prototype of probabilistic early warning systems to predict floods and droughts on a global scale. By providing a comprehensive skill assessment both on a global level and in selected regions we aim at assessing their suitability to be eventually integrated in decision support frameworks.

Keywords: Forecasting, global, extreme events, floods, drought

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Pappenberger, F., Wetterhall, F., Dutra, E., Di Giuseppe, F., Bogner, K., Alfieri, L, Cloke, H.L., 2013, Seamless forecasting of extreme events on a global scale, Climate and Land Surface Changes in Hydrology, Proceedings of H01, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013 (IAHS Publ. 359, 2013).

Ensemble forecasts applied to real-world decision making: the New York City Water Supply Operations Support Tool (OST)

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Abstract:

The New York City Department of Environmental Protection (NYCDEP) operates the City's water supply system, providing more than one billion gallons of high quality water each day to more than nine million residents in the City and in several outside communities. The water is delivered via aqueducts from a 2,000 square mile watershed that extends more than 125 miles from the city. The system is comprised of 19 reservoirs and three controlled lakes with a total capacity of over 550 billion gallons. Releases from the reservoir system support downstream interests including flood attenuation, cold water fisheries and related local economies, aquatic ecosystem support, salt front management, lower basin drought mitigation, and water supply for downstream communities. While NYC's drinking water quality is world-renowned, there are many challenges to providing such water to the tap, including periodic high turbidity episodes in some parts of the reservoir system. These episodes are related to high runoff events, which are occurring more frequently and with increasing magnitude, likely due to climate change. New York City has a waiver from the federal requirement to build a filtration plant, estimated to cost $10 billion to construct and over $100 million per year to operate, and successfully managing turbidity in the system is central to maintaining that waiver. Regulations are becoming stricter and more complex, and public scrutiny of system operations is increasing. Reservoir system infrastructure ranges in age from several decades to more than a century old, thus system operations are increasingly affected by infrastructure outages and repairs. The City is spending nearly $14 billion in coming years to rehabilitate the system and build new infrastructure, and normal water supply operations must continue during this time. New York City thus operates a very complex water supply system in a highly challenging environment and requires cutting-edge scientific tools to do so. To meet this need, NYC worked with a team of consultants and expanded on its existing partnership with the National Weather Service (NWS) to build a decision support system known as the Operations Support Tool (OST). One of the keys to OST is ensemble runoff forecasts, based on NWS Hydrologic Ensemble Forecast Service (HEFS) products, which allow the City to model potential operations *a priori* and assess the range and likelihood of subsequent outcomes. This talk will provide an overview of OST, and present a number of case studies illustrating how OST with HEFS forecasts was used to support water supply system operations. The challenges of using and interpreting probabilistic information in an operational context will be discussed.

Keywords: Operations Support Tool (OST), NYCDEP, ensemble forecasts, HEFS, probabilistic information, filtration avoidance, New York City, water supply.

Ensemble space-time simulation of rainfall from gauge observations with extensive missing records

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Abstract:

Analysis of rainfall observations to estimate rainfall across a catchment is an important step in hydrological modelling for river flow forecasting. In this presentation, we present a hierarchical Bayesian model for ensemble space-time simulation of rainfall from gauge observations with extensive missing records. The model has three levels: (1) spatial variation of long term rainfall including influence of elevation; (2) spatially and temporally structured variation of event rainfall; (3) highly localised and isolated variation of event rainfall including possible measurement error. A number of techniques are used to make the statistical modelling tractable. Zero values of rainfall (dry events) are treated as censored data to allow the use of continuous probability distributions (Wang and Robertson, 2011). A log-sinh transformation (Wang et al., 2012) is applied to the rainfall variable to allow the use of Gaussian distributions. Model parameters, missing data and censored data are inferred in a Bayesian formulation (Song et al., 2014). The use of the three-level hierarchical model makes it possible to use highly efficient Gibbs samplers to numerically infer most of these unknowns. Where Gibbs samplers cannot be analytically derived, one-step Metropolis samplers are used. The model is parameterized for each of the 12 months to allow for seasonal variation. The model may be used to infill missing records, estimate rainfall at ungauged locations, construct rain fields across a catchment, and estimate mean areal catchment rainfall, all in the form of ensembles to represent uncertainty. The model has been applied to daily rainfall data with extensive missing records. Cross validation has been carried out to evaluate the performance of the model in infilling missing records at gauged locations and estimating rainfall at ungauged locations, using the inverse distance weighting method as a benchmark. The model is currently being adapted to hourly rainfall data.

Keywords: Ensemble rainfall analysis, infilling missing records, estimating rainfall at ungauged locations, estimating catchment rainfall

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Yong S., Wang Q.J., Mashford J. and Robertson D. 2014. Multiple imputation of missing data at rain gauges. Draft for submission to Journal of the American Statistical Association.

Statistical techniques in water forecasting

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Abstract:

As we move into an era of probabilistic forecasting, suitable statistical techniques are needed to achieve as much forecast skill as possible and to reliably represent any remaining forecast uncertainty. However, hydrological variables and prediction errors are often not readily amendable to treatment using classical methods from statistical textbooks. In the last few years, our water forecasting research group has developed a number of statistical techniques. This presentation will give an overview of these techniques and their applications.

Examples of the statistical techniques are:

- developing a new transformation for normalising data so that homoscedastic Gaussian distributions can be used (Wang et al., 2012a)
- treating zero (or other threshold) values of data as censored data so that continuous distributions can be used instead of the much less tractable discrete-continuous distributions (Wang and Robertson, 2011)
- using joint probability models to make it easier to deal with non-concurrent data, missing data, zero values, multiple sites and multiple predictands (Wang et al., 2009)
- re-parameterisation of models to speed up solutions (Robertson et al., 2013)
- using hierarchical models to exploit, from data, commonality and individuality of model parameters for different cases (for example seasons and catchments) to reduce model parameter and prediction uncertainty (Li et al, 2013)
- using hierarchical models to break down large and complex problems to smaller and simpler components that are more tractable, leading to more efficient solutions (Song et al., 2014)
- using restricted auto-regressive models for updating predictions to avoid over-correction and degraded performance of base hydrological models (Li et al., 2014a)

- using a multi-stage approach for robust calibration of hydrological models and error updating and quantification models
- using model combination to take advantage of individual strengths of multiple models (e.g. Wang et al., 2012b; Schepen et al, 2014).

Keywords: Statistical methods, probabilistic forecasting, uncertainty

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Yong S., Wang Q.J., Mashford J. and Robertson D. 2014. Multiple imputation of missing data at rain gauges, Draft for submission to Journal of the American Statistical Association.

Do probabilistic forecasts lead to better decisions? Try it yourself!

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Abstract:

The last decade has seen growing research in producing probabilistic hydro-meteorological forecasts and increasing their reliability. This followed the promise that, supplied with information about uncertainty, people would take better risk-based decisions. In recent years, therefore, research and operational developments have also start putting attention to ways of communicating the probabilistic forecasts to decision makers. Communicating probabilistic forecasts includes preparing tools and products for visualization, but also requires understanding how decision makers perceive and use uncertainty information in real-time. In this presentation, we will conduct a laboratory-style experiment in which several cases of flood forecasts and a choice of actions to take will be presented as part of a game to participants, who will act as decision makers. At the end of the game, we will discuss if indeed we make better decisions on the basis of probabilistic forecasts.

Keywords: probabilistic forecasts, flood control, decision-making

A risk-based decision-making game relevant to water management

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Abstract:

Monthly or seasonal streamflow forecasts are essential to improve water planning (eg., water allocation) and anticipate severe events like droughts. Additionally, multipurpose water reservoirs usually integrate hydrologic inflow forecasts to their operational management rules to optimize water allocation or its economic value, to mitigate droughts, for flood and ecological control, among others. Given the need to take into account uncertainties at long lead times to allow for optimal risk-based decisions, the use of probabilistic forecasts in this context is inevitable. In this presentation, we will engage a risk-based decision-making game, where each participant will act as a water manager. A sequence of probabilistic inflow forecasts will be presented to be used to make a reservoir release decision at a monthly time-step, subject to a few constraints – e.g., an end of season target pool elevation, a maximum release and a minimum downstream flow. After each decision, the actual inflow will be presented and the consequences of the decisions made will be discussed together with the participants of the session. This experience will allow participants to experience firsthand the challenges of probabilistic, quantitative decision-making.

Keywords: probabilistic forecasts, water management, risk-based decision making

Evaluation of the satellite-based Global Flood Detection System (GFDS) for estimating river discharge

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Abstract:

Flooding is the most prevalent natural hazard at the global scale, affecting human life and economies. The ongoing refinement of global early warning systems is required to improve the response of international disaster management when an event occurs. These systems can be used for both early forecasting and early detection for an effective response and crisis management.

However, one of the main challenges for global hydrological modelling is the limited availability of observational data for calibration and model verification. This is particularly the case for real time applications. This problem could potentially be overcome if discharge estimates based on satellite data were sufficiently accurate to substitute real time measurements. Although at present, river discharge cannot be measured directly by satellite sensors, Brakenridge et al. (2007) demonstrated that orbital remote sensing can be used to indirectly estimate river discharge changes. The aim of this study is to test the potentials and constrains of the remote sensing signal of the Global Flood Detection System (GFDS) (De Groeve et al., 2006) for converting the flood detection signal into river discharge estimates.

The study drew on data for 335 locations in Africa, Asia, Europe, North America and South America. A calibration of the satellite signal against ground observed discharge was carried out for a period of five years for each station. Estimated discharge was derived and a validation analysis was performed for the following two years. Using this methodology and based on the Nash-Sutcliffe efficiency score, for 162 out of 335 stations the satellite estimated discharge could fill the gaps where observations are not available (Figure 1). For example, several locations in African catchments have good performance as in the Niger, Volta and Zambezi.

This presentation will also illustrate how local conditions can potentially affects the performance of the Global Flood Detection satellite signal to estimate river discharge and the correlation with ground observations. The studied features were the land cover, leaf area index, climatic areas, the potential maxima flood extent, mean daily runoff, upstream catchment area, presence of dams and river ice.

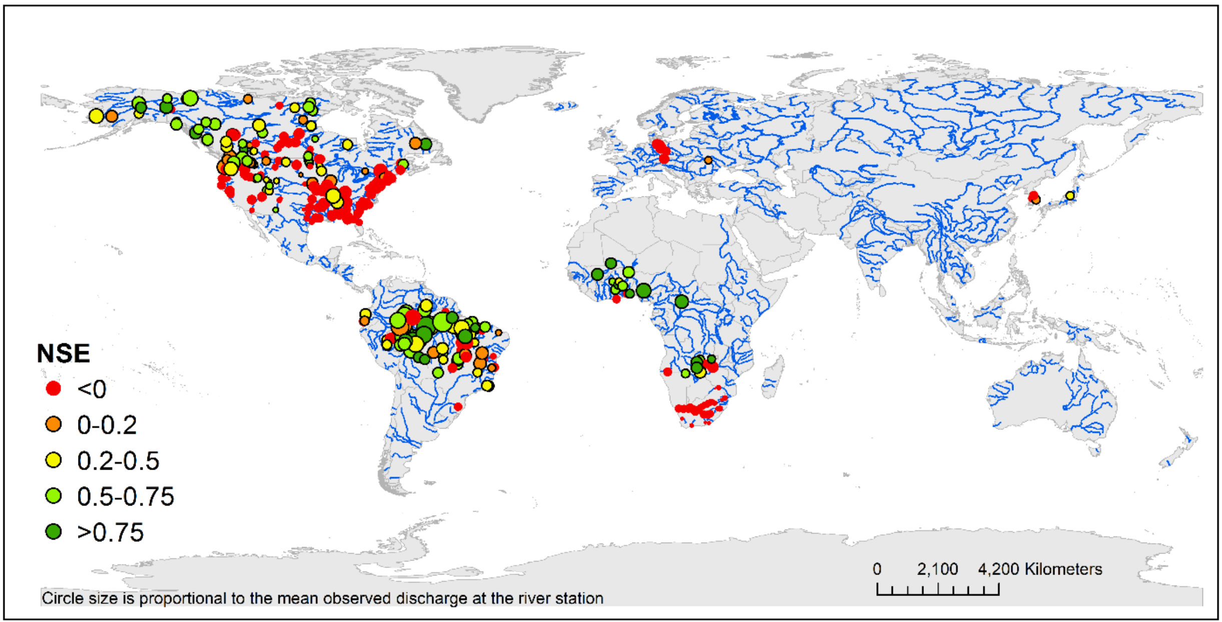

Figure 1. Nash-Sutcliffe efficiency of the validation globally (n= 335 stations). Circle size is proportional to the mean observed discharge at the river station.

Keywords: Flood Detection, Runoff estimation, Global Evaluation

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Does post-processing deterministic numerical weather predictions at multiple time steps lead to better ensemble rainfall forecasts?

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Abstract:

Rainfall forecasts produced by Numerical Weather Prediction (NWP) models typically contain systematic biases when assessed at the catchment scale and many operational models are deterministic. For ensemble streamflow forecasting it is desirable to remove these systematic biases and quantify uncertainty in forecast rainfall using ensembles.

Robertson et al. (2013) described a method to generate bias-free ensemble rainfall forecasts from deterministic NWP forecasts. The method combines a simplified version of the Bayesian joint probability (BJP) modelling approach (Wang et al., 2009; Wang and Robertson, 2011) and the Schaake shuffle (Clark et al., 2004). The BJP modelling approach models the joint distribution of NWP rainfall forecasts and corresponding observations using a log-sinh transformed bivariate normal distribution, treating zero values as censored data. To allow for variation in NWP model bias and model performance with space and time, separate models are established for each location and lead time. Ensemble forecasts are made by generating samples from the joint distribution conditioned on the appropriate value for raw NWP prediction and linking these samples using the Schaake Shuffle.

In this presentation we evaluate the performance of the method described by Robertson et al. (2013) for post-processing catchment rainfall forecasts for 10 catchments covering a wide range of climatic conditions in Australia. We post-process deterministic forecasts from the global version of the Australian Community Climate and Earth Systems Simulator (ACCESS) NWP model, which have lead-times of up to 10 days. The post processing method is applied to 3, 6, 12 and 24 hour rainfall accumulations and evaluated for individual forecast periods and for cumulative rainfall totals. We show that the post-processed ensemble rainfall forecasts are bias free, are more skilful than the raw QPFs, successfully discriminate between events and non-events for small to large precipitation occurrences, and reliably quantify the forecast uncertainty. Importantly, we demonstrate that the time step at which the forecasts are post-processed does not have any significant impact on performance of forecasts of cumulative rainfall totals.

Keywords: Post-processing, numerical weather prediction, ensemble precipitation forecasts, Bayesian joint probability, Schaake shuffle

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A system for continuous hydrological ensemble forecasting (SCHEF) for Australia

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Abstract:

Australian streamflow forecasting services have traditionally focussed on flood events and only been available when anticipated or observed rainfall is significant. Most of these services are based on event models that are initialised at the commencement of a flood. These models can give accurate estimates of flood levels once a hydrograph has commenced rising, but are limited in their ability to forecast flooding at long lead times. Typically, these models have no formal way of estimating the uncertainty in the forecasts, and they rarely make use of quantitative information from numerical weather prediction (NWP) model forecasts.

A new System for Continuous Hydrological Ensemble Forecasting (SCHEF) has been developed for Australia, capable of forecasting streamflows to lead times of 9 days. In the first instance, SCHEF is intended to support optimal management of water resources for consumptive and environmental purposes and ultimately to inform emergency management agencies of impending floods. SCHEF uses forecast rainfall from the ACCESS-G numerical weather prediction (NWP) model (Bureau of Meteorology, 2012) to generate streamflow forecasts. Deterministic NWP rainfall forecasts are post-processed using a technique that combines the Bayesian joint probability modeling approach with the Schaake shuffle (Robertson et al., 2013). The ensemble rainfall forecasts are then used as inputs to a semi-distributed hydrological model to produce ensemble streamflow forecasts. The hydrological model is a variant of the GR4J hydrological model (Perrin et al., 2003; Bennett et al., 2013) to generate sub-catchment runoff and a Muskingum algorithm to route this runoff through a channel network. Observed streamflows are assimilated into the forecasts using an error correction model.

This presentation will provide an overview of SCHEF and describe its performance when applied to 9 Australian catchments with contrasting hydrological and climate conditions. SCHEF was evaluated for a range of forecast time steps to inform decisions about the optimal time step for operational application. Forecast skill is particularly evident at lead times of 1-5 days. Forecast performs the best in temperate perennially-flowing rivers, and the poorest in intermittently flowing rivers. We show that

forecasts generated at 1-hour time steps tend to be more accurate than at longer (e.g. 1-day) time steps. Forecast uncertainty tends to be more reliably quantified at longer lead times than shorter lead times. Current development plans include improving the reliability of uncertainty estimates at all lead times by quantifying errors in the hydrological modeling, obtaining improved estimates of catchment rainfall and uncertainty, and considering a wider range of forecast rainfall products.

Keywords:

Hydrological forecasting; ensemble forecasting; ensemble verification; Numerical Weather Prediction

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Toward ensemble forecasting of water quality

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Abstract:

Short-range water quality forecasting is necessary to protect public health from harmful water quality conditions such as algal blooms or bacterial pollution and to allow the decision makers to respond more quickly to emergency situations such as oil spills. Due to complex hydrologic, hydraulic and biophysiochemical processes involved and limited availability of observations, real-time water quality forecasting is a large challenge. The Water Quality Control Center of the National Institute of Environmental Research currently produces single-valued short-range water quality forecasts for the 4 major river systems in the Republic of Korea. Operational implementation of ensemble data assimilation for watershed and hydro-dynamical models is under way to improve forecast accuracy. To reduce and quantify uncertainties from various sources in the forecast process and to provide reliable uncertainty-quantified forecast information, however, ensemble forecasting is necessary. In this presentation, we describe the status of operational short-range water quality forecasting in Korea, ongoing efforts to improve accuracy, user needs for uncertainty information and plans for ensemble forecasting.

Keywords: forecasting, water quality, short range, uncertainty, user needs

Verification of precipitation forecasts from two numerical weather prediction models as forcing inputs to hydrologic modeling in the Middle-Atlantic River Forecast Center

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Abstract:
Accurate precipitation forecasts are required for accurate flood forecasting. The structures of different precipitation forecasting systems are constantly evolving, with the improvement in forecasting techniques, increases in spatial and temporal resolution, improvements in model physics and numerical techniques, and better understanding of uncertainty. Hence, routine verification is necessary to understand the quality of forecasts in particular locations and as inputs to hydrologic modeling. In this paper, we verify the operational precipitation forecasts from National Centers for Environmental Prediction (NCEP) 21-member Short Range Ensemble Forecast (SREF) system, together with precipitation reforecasts from the 11-member Global Ensemble Forecast System (GEFS). Basin averages as well as gridded precipitation forecasts are verified for several basins in the operating domain of the middle-Atlantic River Forecast Center. Forecast quality is evaluated conditionally upon precipitation amount, seasonality, forecast lead times, and different accumulation periods, and the unique information content of each forecast system is evaluated through partial correlation analysis. The precipitation forecasts are verified with multi-sensor precipitation estimates (MPE) and the sampling uncertainties are assessed with a block bootstrapping technique, which accounts for the temporal dependencies in the verification pairs. The verification results lead to guidance on the expected quality of the precipitation forecasts as forcing inputs to hydrologic modeling, together with an assessment of the relative quality of the precipitation forecasts and unique information content of each system.

Keywords: Precipitation forecasts, Verification

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End-user focussed evaluation and development of ensemble flood forecasts

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Abstract:

Over and under warning of potential future floods is problematic for decision-making, and could ultimately lead to trust being lost in the forecasts. The use of ensemble flood forecasting systems for early warning therefore requires a consideration of how to determine and implement decision-relevant thresholds for flood magnitude and probability, as well as how to evaluate them in a way that is relevant to forecast users. Here we describe the latest progress in a Leverhulme Trust funded project that runs from 2013 to 2016 using the Global Flood Awareness System (GloFAS). The ultimate goals of this project are to improve the usability of ensemble flood forecasts for humanitarian response and to enable forecast system development to be prioritised by what produces the largest gains in decision-making ability.

Work to date has explored the sensitivity of the warning system to the choice of threshold. We use a number of different methods for choosing these thresholds, building on current approaches that use model climatologies to determine the critical flow magnitudes, to those that can provide 'first guesses' of potential impacts (integrating with global-scale inundation mapping), as well as methods that could incorporate resource limitations. The next steps of the project involve developing novel statistical techniques that overcome current methodological limitations in order to validate probabilistic forecasts at the spatial and temporal scales required for decision-making in the face of limited data. This involves collating datasets for evaluation of GloFAS and developing an understanding of how these probabilistic forecasts might be used.

Keywords: Ensemble flood forecasting, end-user needs, decision making under uncertainty

Comparison of quantitative precipitation estimates derived from rain gauge and radar derived algorithms for operational flash flood support over the Hawaiian Islands

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Abstract:

Flash flooding on the Hawaiian Islands cause property damage and the occasional loss of life. The islands have extreme spatial precipitation gradients and a large range of temporal rain rate intensities. These characteristics lead to inherent uncertainty in radar and rain gauge derived precipitation estimates and imply a need for development of precipitation uncertainty information. To better provide continuous flash flood situational awareness and to better differentiate severity of ongoing individual precipitation events, the National Weather Service Research Distributed Hydrologic Model (RDHM) is being implemented over Hawaii. In the implementation process of RDHM, two independent gridded precipitation analyses are used as forcing for RDHM. The first analysis is a radar only precipitation estimate derived from WSR-88D digital hybrid reflectivity, a tropical Z-R relationship and aggregated into an hourly ¼ HRAP grid. The second analysis is derived from the Hawaii rain gauge network and interpolated into an hourly ¼ HRAP grid using PRISM climatology. Spatial and temporal differences between the two analyses appear at different scales. To assess the differences and to identify a preferred analysis for operational use, each was used to force RDHM using a-priori static parameters to simulate stream flow at USGS gauge locations in Hawaii. Results from the stream flow simulations over an initial two year period focused on peak flow assessment and did not consistently indicate one analysis performed better than another. To better assess specific differences between the two different precipitation analyses. A running mean difference and variance from each analysis were compiled by grid cell for time horizons ranging from multiple hours to weeks. These statistical summary grids show how the radar and rain gauge analyses vary over different time periods, intensities, and spatially as well as potentially plausible range for a precipitation estimate. The implications of this while only subjective advocate that more robust operational algorithms are needed for generating probabilistic quantitative precipitation for tools like RDHM and other National Weather Service flash flood tools. Work by Krajewski and Ciah (2006), Seo and Breidenbach(2002), and others show there are robust methods for generating gridded precipitation uncertainty and or directly generating probabilistic precipitation estimates that could be used by forecasters to improve operational flash flood decision support.

Keywords: flash flooding quantitative precipitation estimates

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Does consideration of the initial condition uncertainty improve multimodel ensemble forecasts?

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Abstract: Hydrological ensemble prediction systems offer the possibility to dynamically asses forecast uncertainty. More specifically, multimodel ensembles are a mean to decipher uncertainty related to structures and parameters[1]. The interest towards the use such system has been recently highlighted[2]. Yet, the multimodel approach may not encompass fully the forecasting uncertainty and initial conditions need to be taken into account. Data assimilation, coupling observations and forecast, tends to quantify and reduce initial conditions uncertainty issuing more reliable and sharper forecasts. For that purpose, ensemble Kalman filtering technique (EnKF) is used here for correcting model states as observations are made available. This contributes to compensate for the lack of knowledge in operational forecast system data assimilation[3] and a first for multimodel ensemble sequential data assimilation.

This study aims at evaluating performances in terms of accuracy and reliability of an ensemble composed of 20 lumped models chosen for their structural and conceptual diversity. The multimodel ensemble is coupled with a deterministic meteorological weather forecast and tested on more than 2 years of a 6-day ahead forecasts and 38 catchments under important nival influence.

Since the multimodel presents a range of different structures, the possibilities for applying EnKF are many. This motivates a thorough investigation to reach an optimal framework for initial conditions uncertainty handling. A guide line to make best use of EnKF for multimodel ensemble is suggested. A state sensitivity study and a model state correlation analysis are carried out to identify the states which should be updated in priority, the number of states and the way they should be updated. Hidden models state variables are then either updated jointly or individually based on streamflow observations. Perturbation of the inputs and methods to ensure the Gaussianity required for EnKF inputs are also discussed. Finally, a comparison is performed between forecast issued from updated initial states and from a simple correction technique for short and medium-range lead times. Thereby, optimal implementations are drawn for each model composing the ensemble and an identification of hydrological models structures more compatible with initial condition uncertainty managing is made possible.

Keywords: Multimodel ensemble, Operational forecasting, Ensemble Kalman Filter, Data assimilation

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Global flood forecasting and detection in support to a Global Flood Partnership

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Abstract:

Climate change, population increase, urbanisation and land use changes are likely factors to increase the impact of floods worldwide. Not all nations have adequate national flood monitoring and forecasting systems in place and are therefore particularly vulnerable. In order to address the gaps and increase resilience, International cooperation is important to fill the gaps in data collection and processing, remote sensing detection methods, and in forecasting capabilities using state of the art numerical weather prediction data. With increased availability of remote sensing data and new generations of weather and flood forecasting models, building global flood forecasting and monitoring systems is feasible and such systems are able to provide information useful for operational response and flood risk management.

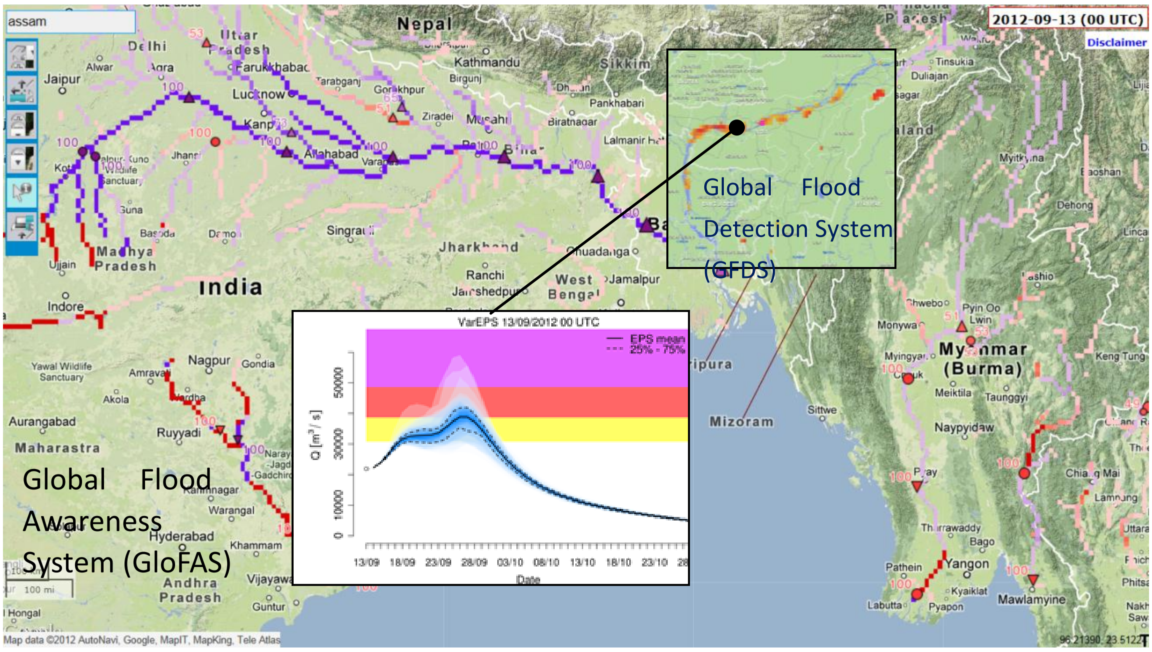
In this context, a concept for a Global Flood Partnership [1]is being proposed to provide operational, globally applicable, flood forecasting and monitoring tools as well as services, complementary to national capabilities, for better managing current and future flood risk and reducing flood disaster impacts. The Global Floods Partnership should be complementary to existing initiatives at global level.

Current research at the JRC has demonstrated the feasibility to operate flood forecasting and observation systems at global level that can potentially provide information accurate enough to be beneficial for national disaster management services. The services are intended to be complementary to the more detailed national systems, but informative enough for authorities to start preparedness actions, in particular for international river basins.

This presentation will be illustrating how combining the Global Flood Awareness System (GloFAS, Alfieri et al, 2012) with the Global Flood Detection System (GFDS, de Groeve 2010) can provide a chain of useful information for decision makers. While GloFAS is based on ensemble prediction system inputs and produces probabilistic output of critical flood exceedance levels up to 30 days in

[1] http://portal.gdacs.org/Global-Flood-Partnership

advance, the Global Flood Detection System (GFDS) uses passive microwave satellite information to detect an increase in water surface. Naturally, both flood forecasting and detection systems have limitations, but by combining the information from both systems, floods can be addressed more comprehensively than with individual systems only. Figure 1 illustrates how both systems can interact.



Keywords: Flood Detection, Flood Forecasting, Global Flood Partnership

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Estimating predictive hydrological uncertainty by dressing deterministic and ensemble forecasts: a comparison, with application to Meuse and Rhine

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Abstract:

Hydrological forecasts are characterised by uncertainties originating in the meteorological forecasts as well as in the modeling of streamflow generation and routing processes. Estimates of predictive hydrological uncertainty therefore have to be inclusive of both meteorological and hydrological uncertainties. Generally speaking, there are two approaches to estimating this 'holistic' predictive uncertainty: a source-specific approach where uncertainties from each source are estimated separately and subsequently integrated, and a lumped approach where all uncertainties are estimated using a single technique.

The present paper explores an 'in between' approach, often referred to as 'ensemble dressing'. Uncertainties in the predicted meteorological forcings are estimated using an ensemble approach, the remaining uncertainties are lumped using a statistical post-processor and the two estimates are combined to arrive at an estimate of total uncertainty.

Skill and quality of forecasts in four scenarios are inter-compared: 'bare' deterministic and ensemble streamflow forecasts and their 'dressed' equivalents. This evaluation shows that, generally, (i) bare ensemble forecasts have higher skill than bare deterministic forecasts; (ii) dressed forecasts have higher skill than their bare equivalents; (iii) the skill of dressed ensemble forecasts is roughly equal to that of dressed deterministic forecasts. These conclusions are discussed with respect to what constitutes a possible 'best' approach for estimating predictive hydrological uncertainty.

Keywords: Hydrological forecasting; Predictive uncertainty; Quantile Regression; Error correction; Meuse; Rhine ; Ensemble dressing; Ensemble techniques; Statistical post-processing; Forecast verification.

On the effective use of probabilistic forecasts in flood forecasting, warning and response systems

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Abstract:

The primary reason for forecasting is to realise value - a user's benefit, either economic or other - by reduction of uncertainty about the future. Benefits may vary from application to application. In flood forecasting, decision and response systems (FFDRS, sometimes referred to as flood early warning systems), the aim is generally to reduce the adverse effects of flooding. Either the flood hazard itself is mitigated or timely warning is given to a community at risk, thus allowing for implementation of measures aimed at reduction of damage, casualties or both.

While forecasting can indeed reduce uncertainties about future values of hydrologic variates, these uncertainties cannot be fully eliminated. Increasingly often, the remaining uncertainty is explicitly estimated probabilistically and communicated to forecast users. These probabilistic forecasts thus constitute estimates of the distribution of future values of hydrologic variates.

Prescriptive studies of forecast value suggest that forecasts that are enhanced by estimates of predictive uncertainty have higher value than those that are not. The reason for this is that the estimate of predictive uncertainty can be taken into account in the decision-making processes. To wit, a probabilistic forecast allows for weighing possible scenarios with the probability of occurrence thereof, thus enabling risk analyses.

Descriptive studies, however, suggest that the maximum potentially value of forecasts is often not obtained. Reasons for that include (i) misunderstanding or misinterpretation of the forecast and (ii) non-use or non-optimal use of forecasts. Thus, the forecasts are not used as effectively as they potentially could have been.

We hypothesize that the very nature of probabilistic forecasts introduces challenges that, in current operational practice, hamper fully effective use thereof. These challenges arise in various online (i.e. real-time) and offline (i.e. not real-time) system components or protocols, including forecast visualisation, communication, decision-making, training and verification.

In the present work, it is identified which challenges are relevant, whether best or bad practices pertaining to these challenges exist, and what constitutes a promising development path for flood early warning systems that make use of probabilistic forecasts.

The approach taken in this study is as follows. First, a simple model of a forecast, decision and response model is outlined; this model aids the subsequent analysis. Second, an inventory of potential issues, or challenges, is made by means of a literature review as well as expert solicitation. Subsequently, a conceptual model of FFDRS development - the Staged Development Model - is created, to which case study systems are subjected. From the analysis, best practices are identified. Finally, the results are discussed.

Keywords: flood early warning; flood forecasting; predictive uncertainty; forecast value; effective use.

hepex.org: serving the hydrometeorological forecasting community

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Abstract:

HEPEX meetings are generally well attended, much appreciated and preceded as well as followed by a flurry of activity. In between meetings, unfortunately, activity tends to die down. As we'd like to people to be engaged continuously, we need alternative ways of engaging the community.

For that purpose, a new HEPEX web portal was created. The portal is based on the concept of “blogging”, i.e. consists of highly dynamic content. This blog format allows for easy addition of new content as well as for interaction, through comments, by the HEPEX community. Since inception, some dozens of new blog items have been posted which in turn elicited hundreds of comments. In addition, the portal also serves as a repository for “resources”: presentation slides, a list of HEPEX related special issues, games, training tools, and more.

The portal is also a central feature in the HEPEX online presence. Additional ‘online products’ include periodical webinars, a HEPEX LinkedIn Group, a Twitter handle, a YouTube channel and a paper.li daily newspaper. In addition to these, HEPEX volunteers are thinking about a Facebook page, a Google Plug page and increased coverage on Wikipedia.org.

Judging from visitor counts (currently – mid February – well over 20,000), online debate and discussions and the responses received by the authors, the online presence is indeed contributing to a continuously engaged HEPEX community.

This contribution to the June 2014 HEPEX meeting will give some additional details about the online presence as well as share some ideas for further expansion thereof. By doing so, the authors hope to attract additional visitors and maybe inspire additional online activities that contribute to the HEPEX mission and further strengthen its community.

Keywords: HEPEX; community; portal

Cost of inflow forecast uncertainty for day ahead hydropower prodcution scheduling

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Abstract:

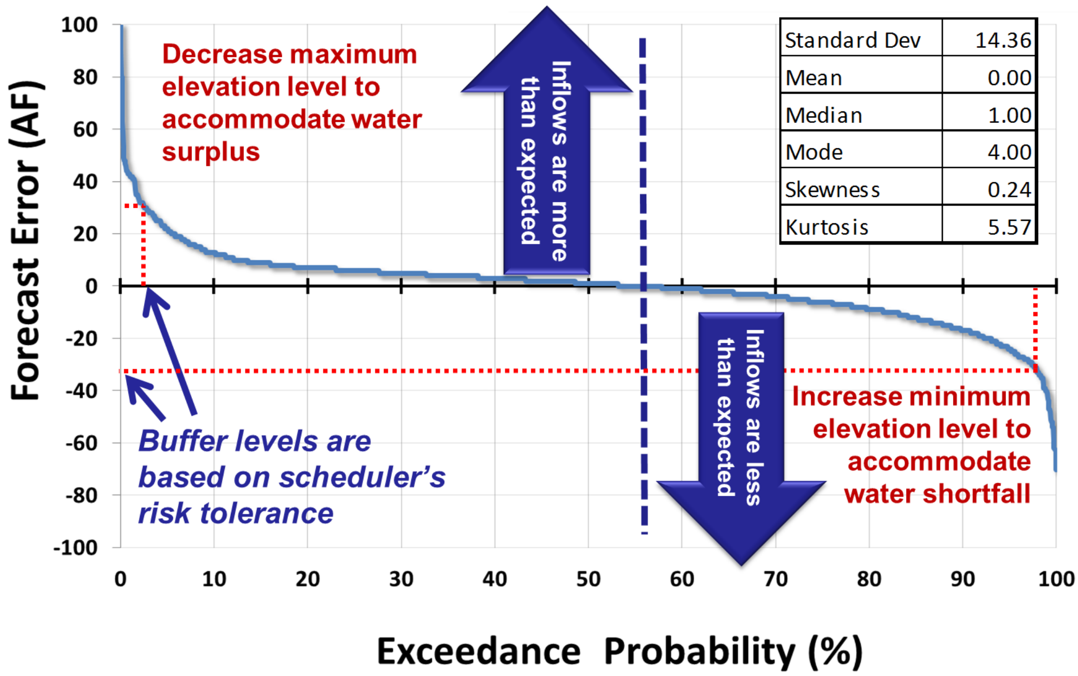
The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Water Power Program, funded a team of national laboratories to build the Water Use Optimization Toolset (WUOT). This suite of advanced, integrated analytical tools was designed to assist managers and planners increase the value of hydropower resources while enhancing the environment. This presentation discusses the use of the WUOT Conventional Hydropower Energy and Environmental Systems (CHEERS) model to manage risks associated with water inflow forecast error. Developed at Argonne National Laboratory, CHEERS is a day-ahead scheduling and real-time operations optimization tool.

WUOT is currently being demonstrated at the tightly coupled Aspinall Cascade located in the Colorado River Basin. The cascade is a multipurpose system consisting of the Blue Mesa Dam at the top, followed by Morrow Point and then Crystal. Cascade operations takes into consideration power generation, flood control needs, existing water rights, minimum in-stream flows, flow needs for endangered fish and other resources, recreation, and other factors. Crystal Reservoir operations are tightly constrained. Water elevation is highly sensitive to storage volume and is subject to significant measurement error. Also, Crystal side flows are both highly variable and difficult to accurately predict. These uncertainties result in reservoir elevations that occasionally differ from predicted levels. Therefore, reservoir elevation limits are at risk of being violated and potentially force costly deviations from day-ahead schedules. To help schedulers cope with these challenges, CHEERS employs a probabilistic approach that estimates situational side flow forecast error based on historic data and ensemble results from an inflow forecasting tool.

CHEERS uses upper and lower reservoir buffers to reduce, but not eliminate, costly real-time water management adjustments and potential reservoir elevation violations. As illustrated in the figure below, at the upper range of the reservoir elevation level, the buffer is filled when actual inflows are greater than predicted. The opposite occurs at lower reservoir elevations and the buffer is drained when inflows are less than expected. The use of reservoir buffers reduces potential reservoir violations; however, the narrower operating range diminishes the economic and financial value of power by reducing the operational flexibility of plant operations. A smaller risk level than the one shown in the illustration below will reduce the frequency of potential reservoir violations. However, potential

economic costs will increase. Therefore, there are tradeoffs between buffer size and economic costs.

During the presentation we will discuss Aspinall forecast error exceedance curves operational risks, and the use of CHEERS to examine tradeoffs between risk and economics. Lastly we will discuss the economic value of improved inflow forecasts.



Keywords: reservoir, hydropower, cascades, uncertainty, risk, economics

Lesson-learnt from developing a multi scale ensemble hydrologic forecast system customized for optimization of flow control operations

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Abstract:

In the US, most of the reservoirs with significant hydropower capacity have limited flexibility to operate due to the other primary uses. The US Department of Energy Streamflow Water Use Optimization Project aims at improving the hydropower generation by improving the integration of the different modeling steps driving to the decision of the hydropower operation margin. The steps, hereafter referred to as tools, include hydrological forecasting, environmental conservation needs, seasonal reservoir operations optimization, short term optimization of ancillary services. As part of the project, all tools' developers have been working closely together and along with the end-users - energy providers and reservoir operators, in order to refine the end products of each tool to be coupled or integrated in the overall system.

We present the lessons learnt during the development of a multi-scale ensemble flow forecast system, customized specifically to be integrated into a multi-purpose reservoir operations optimization toolset. We start by reviewing the widely available flow forecast products and how they are used by reservoir optimization system. We follow with the description of the Water Use Optimization Toolset and the specifications required from the hydrologic forecast tool. We then discuss how current systems meet the specifications, the customized products our system provides, which ongoing research and development can address the other tools' wish list, and discuss remaining challenges. Finally we specifically discuss the integration of ensemble flow forecast in the multi-purpose operating system.

Keywords: reservoir operations, ensemble streamflow forecast, integrated modelling, optimization

NWS Hydrologic Ensemble Forecast Service (HEFS): effectively communicating uncertainty via products and information

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Abstract:

NWS River Forecast Centers (RFCs) currently issue two primary types of streamflow forecasts: (1) deterministic streamflow forecasts for lead times from hours out to 10 days, updated one or more times daily; and (2) ensemble streamflow forecasts for lead times of a month out to approximately one year. Providing uncertainty ranges for hydrologic forecasts at all time scales – from short-range flood forecasts to the current longer lead water management products– is one of the most pressing needs of operational hydrologic forecasting [National Research Council report (2006), customer surveys, and multiple NWS flood service assessments].

The NWS is currently engaged in a multi-year project to develop and implement a new Hydrologic Ensemble Forecast Service (HEFS) at our thirteen RFCs to meet this need. This short- to long-term ensemble forecasting capability will provide a new suite of information regarding forecast uncertainty. These new probabilistic forecasts should: (1) provide NWS forecasters with objective guidance for confidence in hydrologic forecasts improving hazard products, hazard issuance, and decision support services to our customers; and (2) provide information for users to make better and more informed decisions (including flood risk management decisions). Previous customer satisfaction surveys, customer engagement, and experience with long-term uncertainty products and experimental short-term uncertainty products have provided a foundation for the types of products and information users require. We will discuss the project with a focus on new products and maximizing the utility of this information to users (e.g., flood risk managers, NWS WFO forecasters, Emergency managers, and media partners).

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Ensemble modeling to improve hydropower generation and flood forecasts in the American River Basin

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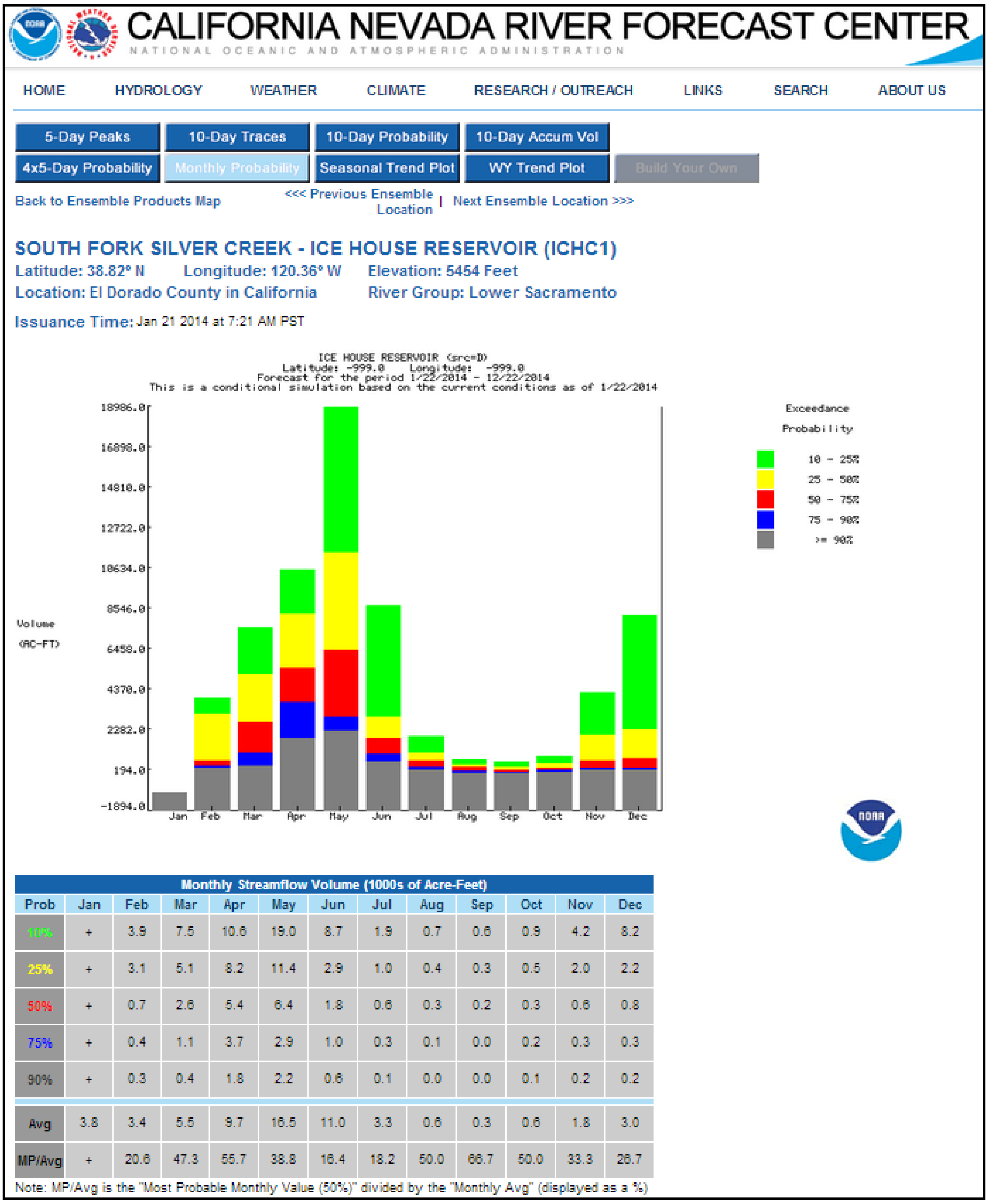
Abstract:

The California Nevada River Forecast Center (CNRFC) reconfigured and re-calibrated the American River watershed within its hydrologic model in the fall of 2012 in order to better meet the needs of the Sacramento Municipal Utilities District (SMUD) and Placer County Water Agency (PCWA). SMUD and PCWA operate a series of reservoirs and associated hydroelectric plants in the upper American River watershed and they rely in part on CNRFC forecasts in their operations. This collaborative effort with SMUD and PCWA could serve as a model for data sharing, hydrologic model re-configuration, and data formatting for similar efforts in other watersheds.

The reconfiguration strategy subdivided existing basins to isolate the various reservoirs used in hydropower operations. This strategy allows for customized inflow forecasts for each reservoir which in turn allows operators to better manage the reservoirs for day-to-day operations and for flood control operations when those conditions are present. The meteorological inputs used in CNRFC hydrologic forecasts consist of five days of forecaster-modified Quantitative Precipitation Forecasts (QPF), temperature, and freezing level, at six hour intervals. Furthermore, the CNRFC started providing ensemble forecasts to SMUD and PCWA in a comma-separated format that allows them to integrate these forecasts into their long-term power generation planning. The forcings for these ensemble forecasts are based on the short-term meteorological inputs used in the deterministic forecasts, medium range numerical model forecasts (out to 14 days) from a frozen version of the Global Forecast System model, and nearly 60 years of climatology. One example forecast product is shown in Figure 1.

The American River watershed is experiencing one of the most severe droughts in California over the past century. As of January 3, 2014, California's snowpack was just 20% of normal. January precipitation has been virtually non-existent as the drought persists. The next snow survey is expected to show even lower amounts as a percentage of normal.

The ensemble forecasts are proving highly valuable in guiding SMUD's hydropower operations under severe drought. Previously, decision-makers relied on statistical regressions which break down under extreme conditions.



Monthly Streamflow Volume (1000s of Acre-Feet)												
Prob	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10%	+	3.9	7.5	10.6	19.0	8.7	1.9	0.7	0.6	0.9	4.2	8.2
25%	+	3.1	5.1	8.2	11.4	2.9	1.0	0.4	0.3	0.5	2.0	2.2
50%	+	0.7	2.6	5.4	6.4	1.8	0.6	0.3	0.2	0.3	0.6	0.8
75%	+	0.4	1.1	3.7	2.9	1.0	0.3	0.1	0.0	0.2	0.3	0.3
90%	+	0.3	0.4	1.8	2.2	0.6	0.1	0.0	0.0	0.1	0.2	0.2
Avg	3.8	3.4	5.5	9.7	16.5	11.0	3.3	0.6	0.3	0.6	1.8	3.0
MP/Avg	+	20.6	47.3	55.7	38.8	16.4	18.2	50.0	66.7	50.0	33.3	26.7

Note: MP/Avg is the "Most Probable Monthly Value (50%)" divided by the "Monthly Avg" (displayed as a %)

Figure 1: Example Exceedance Probability Forecast for Monthly Streamflow Volumes

Keywords: hydrology, drought, hydropower, ensemble, forecast

Combine ensembles with inundation mapping to visualize flood forecast uncertainty

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Abstract:

Probabilistic forecasts of flood elevations arising from ensemble streamflow forecasts are becoming more and more prevalent. Probabilistic forecasts are often presented as exceedance forecasts (e.g. 90% chance of exceeding a stage of 10 feet, 50% chance of exceeding 14 feet, and 10% chance of exceeding 18 feet.) Interpretation of this information by local decision makers is sometimes difficult.

Flood inundation mapping is an excellent tool to help decision makers visualize what areas of a community are threatened by a given flood. They can see what areas may flood as well as the timing of inundation at certain locations. However, inundation maps tied to a specific flood elevation may imply a level of accuracy that is not warranted. The “hard” edge to a projected inundation area may imply that the flooding will stop at a particular spot or along a particular line. Current flood forecasts simply have too much uncertainty to warrant that much confidence.

This presentation will examine different ways flood inundation maps can be used to visually express reasonable ranges of potential inundation areas; enabling decision makers to see uncertainties in potential inundation. Figure 1 presents an example use of inundation maps showing a range of possible inundation areas associated with varying levels of confidence.

Keywords: hydrology, hydraulics, flood, inundation, ensemble, forecast

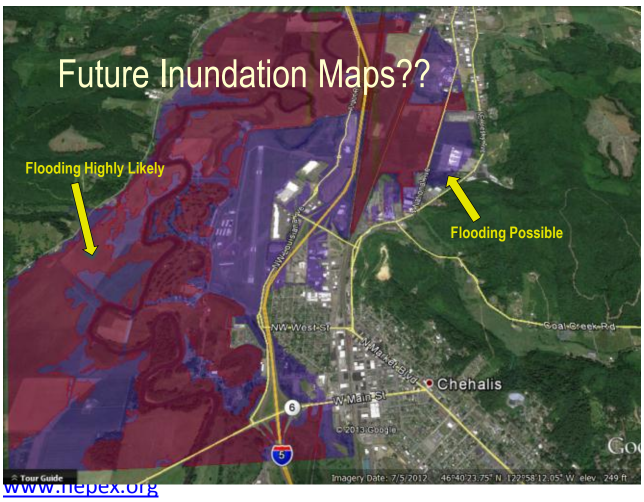

Figure 2: Example Inundation Map Showing Forecast Uncertainty

Forecaster priorities for improving probabilistic flood forecasts

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Abstract:

Hydrological ensemble prediction systems (HEPS) have in recent years been increasingly used for the operational forecasting of floods by European hydrometeorological agencies. The most obvious advantage of HEPS is that more of the uncertainty in the modelling system can be assessed. In addition, ensemble prediction systems generally have better skill than deterministic systems both in the terms of the mean forecast performance and the potential forecasting of extreme events. Research efforts have so far mostly been devoted to the improvement of the physical and technical aspects of the model systems, such as increased resolution in time and space and better description of physical processes. Developments like these are certainly needed, however, in this paper we argue that there are other areas of HEPS that need urgent attention. This was also the result from two a group exercise and a survey conducted to operational forecasters within the European Flood Awareness System (EFAS) to identify the top priorities of improvement regarding their own system. They turned out to span a range of areas, the most popular being to include verification an assessment of past forecast performance, a multi-model approach for hydrological modelling, to increase the forecast skill on the medium range (>3 days) and more focus on education and training on the interpretation of forecasts. In light of limited resources we suggest a simple model to classify the identified priorities in terms of their cost and complexity to decide in which order to tackle them. This model is then used to create an action plan of short-, medium- and long-term research priorities with the ultimate goal of an optimal improvement of EFAS in particular and to spur on the development of operational HEPS in general.

Keywords: Hydrology, ensemble, forecasting, operational.

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Relating seasonal streamflow forecast skill to uncertainties in initial conditions, future forcings, and hydrologic modeling

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Abstract:

Skill in model-based hydrologic forecasting depends on the ability to estimate a watershed's initial moisture and energy conditions, to forecast future weather and climate inputs, and on the quality of the hydrologic model's representation of watershed processes. The impact of these factors on prediction skill varies regionally, seasonally, and by model. We investigate these influences in a series of predictability experiments using calibrated hydrologic simulation models for a 630-watershed dataset that spans the continental US (CONUS), and using the current major simulation models of National Weather Service streamflow forecasting operations. Earlier work in this area outlined an ensemble-based strategy for attributing streamflow forecast uncertainty between two endpoints representing zero information about future forcings (ie, the NWS ensemble streamflow prediction, or ESP approach) versus zero information about initial conditions (termed 'reverse-ESP'). This study adopts a more comprehensive approach to characterize the effects of varying levels of uncertainty, from zero knowledge to perfect information in the model world, on streamflow prediction uncertainty. Ensemble hindcasts reflecting varying levels of uncertainty are initialized on a monthly basis for the basins' periods of record, creating background sensitivity information that helps to decompose total hydrologic prediction error into the three components identified above. Observed streamflow prediction errors are then coupled with estimates of realistic uncertainties in future forcing and with model simulation error to infer initial condition errors. This presentation reports findings from the predictability experiments, summarizing the relative importance of uncertainties in basin initial conditions and weather and climate forecasts, and their dependence on forecast lead time, initiation date and regional hydroclimate characteristics.

Keywords: seasonal streamflow predictability, watershed modelling

Assessing short to medium range ensemble streamflow forecast approaches in small to medium scale watersheds across CONUS

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Abstract:

As part of the Hydrologic Ensemble Forecast Service, the US National Weather Service River Forecasting Centers have implemented short to medium range ensemble streamflow forecasts. Hydrologic models are forced with meteorological forecast ensembles using a downscaling and calibration technique, MEFP, that leverages correlations at multiple temporal scales between large scale GEFS forecast ensemble mean and local scale observed precipitation and temperature. Strengths of MEFP include its use of multi-decade hindcast for calibration of local scale forecasts and production of verification information, but possible weaknesses include the use of precipitation and temperature ensemble mean information only, which requires the statistical synthesis of ensemble members. We explore whether using a larger set of atmospheric predictors and full ensemble members from the GEFS can lead to greater meteorological and hydrological predictability. Using 30+ year streamflow hindcasts, we evaluate 1-15 day streamflow predictions using the Snow-17/Sacramento hydrologic modeling approach in small to medium-sized watersheds across CONUS. We compare the MEFP approach and performance with regressive and analog-based statistical downscaling and calibration methods that rely on a range of atmospheric predictors to produce watershed-scale ensemble forecasts. This presentation briefly describes the implementation of the hindcasting experiments on the NCAR Yellowstone supercomputer, before contrasting the strengths and weaknesses of the two approaches.

Keywords: ensemble streamflow forecasting, HEFS

Linking the hydrologic and atmospheric communities through probabilistic flash flood forecasting

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Abstract:

NCEP's Weather Prediction Center (WPC) provides national quantitative precipitation forecast (QPF) guidance, including flash flood outlooks and short-term Mesoscale Precipitation Discussions (MPDs). MPDs are event-driven forecasts that highlight regions where heavy rainfall may lead to flash flooding in the next 1-6 hours. WPC has focused on probabilistic approaches, providing probabilistic QPF for the community, as well as probabilistic flash flood risks. In support of these functions, and in an effort to better link the hydrologic and atmospheric communities, the Hydrometeorological Testbed at WPC (HMT-WPC) collaborated with the atmospheric and hydrologic communities to host the Flash Flood and Intense Rainfall Experiment (FFaIR) during July 2013. The experiment brought together a total of 26 forecasters, researchers, and model developers, including 8 participating remotely, to explore the challenges associated with short-term probabilistic QPF and flash flood forecasting during the warm season. During the experiment, participants used a combination of operational and experimental numerical model guidance to issue several short-term probabilistic QPF and flash flood forecasts. The experimental guidance included a new version of the operational North American Model (NAM, 12 km with 4 km nest), the High Resolution Rapid Refresh (HRRR, 3 km), the Storm Scale Ensemble of Opportunity (SSEO, 7 members, 4 km), and the Experimental Regional Ensemble Forecast System (ExREF, 8 members, 9 km). Both experimental ensembles featured a variety of point and neighborhood exceedance probabilities, including probabilities of QPF exceeding flash flood guidance. Participants were also asked to subjectively evaluate their experimental forecasts, the quality of various flash flood indicators, and the experimental model guidance. As part of the evaluation process, participants were introduced to Flooded Locations and Simulated Hydrographs (FLASH), a high resolution rapidly updating hydrologic model used to identify locations of flash flood events. The 2013 Flash Flood and Intense Rainfall Experiment highlighted the numerous challenges associated with short-term flash flood forecasting and the 2014 experiment is being planned. This presentation will provide an overview of the 2013 experiment, show preliminary results from the subjective evaluations, and highlight lessons learned. Further, plans for the July 2014 Flash Flood and Intense Rainfall Experiment will also be highlighted. Finally, the impact on WPC's operations will be discussed.

Keywords: Probabilistic QPF, Flash Flood, Forecasting

Comparison of different efficiency criteria for hydrological ensemble prediction assessment

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Abstract:

With the increasing practical issues, such as flood estimation, drought forecast and water resources management, the demand for the hydrological ensemble prediction is rising. However, what is a good forecast? Is there any appropriate and accurate efficiency criteria can help us evaluate the forecast as "good", "bad" or "skilful"? Moreover, among the existing various criteria of verification methods, an in-depth study of evaluating and formulating these criteria is very meaningful.

Because of the emphasis in the suitability of different criteria may vary according to different situations (such as its reliability and sensitivity to the hydrological regime or sample size), the experimental design was constructed in three sections of this paper: 1) the continuous simulation (flow/precipitation), 2) high-flow or low-flow simulation, 3) the torrential rain simulation. And the criteria were evaluated using seven rainfall-runoff models and twelve catchments located in U.S.

Relationships among the various criteria were considered. The merit and demerit of the criteria were analysed. The suitability and effectiveness of different criteria were also discussed. It's revealed that the quality of Quantile-Quantile plot and rank histogram is same, just formally has distinction. And these two criteria are both keenly sensitive to zero members in the precipitation. Moreover, like many other criteria based on statistical principles, the reliability diagram are limited to the data sample size and the forecast threshold scheme.

Keywords: Hydrological ensemble prediction verification, Efficiency criteria, Experimental design.

Climatological analysis of model precipitation from NCEP GEFS reforecast

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Abstract:
ESRL/PSD GEFS Reforecast V2 is an extensive dataset of historical weather forecasts generated with NCEP's 2012 operational Global Ensemble Forecasting System (GEFS) version for past 28 years. It is developed mainly for the purpose of a number of applications, including statistical post-processing, diagnosis of the forecast ability of uncommon phenomena and initialization of regional model reforecasts. In particular, this long reforecast dataset gives us an unprecedented opportunity to develop a dataset of model precipitation climatology for GEFS, which could be used for forecast calibration and verification studies and anomaly forecast guidance. Due to non-Gaussian feature and heavy-tailed distributions of precipitation amount, the L-moment method with Gama distribution as a fitting function was employed to derive the NCEP Climatology-Calibrated Precipitation Analysis (CCPA) daily climatology in our previous study, and also is utilized here to calculate model daily climatology based on 26 years (1985-2010) of the GEFS Reforecast as well. Furthermore, it is necessary to evaluate model climatology from the Reforecast dataset. In this study, CCPA climatology for a period of 8-years (2002-2010) is used to evaluate Reforecast climatology with the coincident period for the Contiguous United States (CONUS) domain and each River Forecast Center (RFC). These datasets are compared at 1-deg grid resolution and various time scales ranging from daily, monthly to seasonal time scales. Detailed comparisons are provided to decide a selection of sampling methods in the calculations of daily climatology, to assess the quality of Reforecast and to understand the error characteristics associated with the Reforecast precipitation. Preliminary results show good overall agreement between the CCPA and the Reforecast over CONUS in the shortest lead time. However, agreement has a wide variety from one RFC to another and from short to long forecast lead time, as we find that the strength of the correlation and model bias varies significantly from one RFC to another. Our preliminary conclusions suggest that the GEFS Reforecast could provide a useful precipitation climatology dataset for our future applications, such as forecast calibration and verification, and anomaly forecast generation.

Keywords: Model Precipitation Climatology, L-Moment Method, Reforecast

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Operating rules derivation considering hydrologic uncertainty: taking the Jinsha River System as example

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Abstract:

Hydropower optimal operation has been one of the most challenging optimization tasks in power systems for several decades, mainly due to the uncertainty nature of inflows. Assuming inflows in all time steps available, theoretically global optimal solution can be achieved using dynamic programming (DP) theory and its proceedings. However, deterministic optimization with perfect knowledge of all future flows is not the case with actual real time operations. To implement actual optimal operation of large scaled hydropower system with limited inflows, this paper makes use of Parameter Calibrated Support Vector Regression (PCSVR) algorithm to derive optimal operating rules. The trained SVR model describes the complex nonlinear relationships between reservoir operation decisions and factors by considering both generalization and regression performance, which overcomes local optimization and over fitting deficits. Grid searching and cross validation are incorporated to improve the SVR performance. This PCSVR model is applied to the largest hydropower base in southwestern China – Jinsha cascade system with twelve cascaded hydropower stations. Three scenarios with different inflows predict precision are implemented: 5% predict precision, 10% predict precision and 15% predict precision. Simulation results indicate that, annual power generation with 5% inflows predict precision is 39879MW, while annual power generation with 10% and 15% inflows predict precision are 39245 MW and 36924 MW. Annual power generation with perfect overall inflows accounts for 41633 MW. The results demonstrate that PCSVR based operating rules achieve favorable performance, for the power generation gap between deterministic operation and simulation is acceptable. Besides, comprehensive comparison among different simulation scenarios reflects how more precise inflows prediction contributes to system power generation as well as power generating process. Consequently, the PCSVR approach and case study discussed in this paper provides valuable information for optimal operation under actual uncertain inflows.

Keywords: inflows uncertainty, reservoir operation, support vector regression, simulation, prediction precision

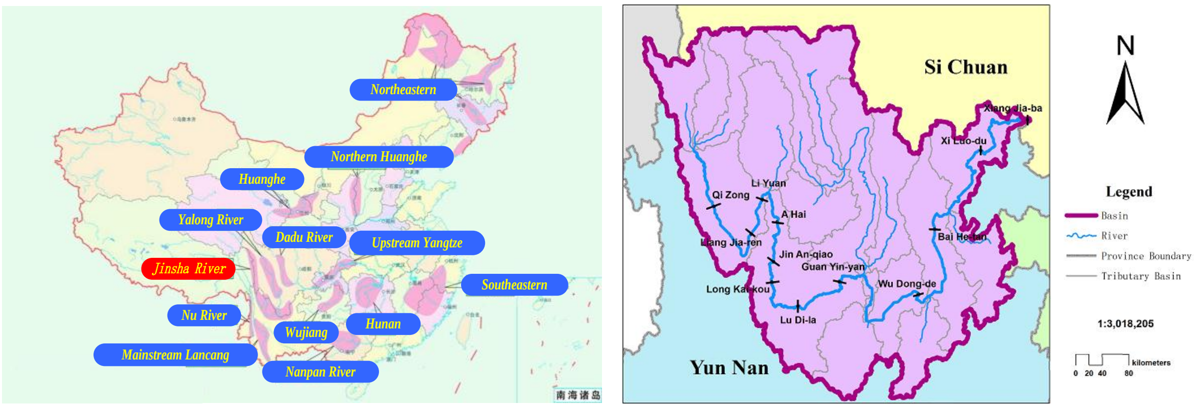

Figure: Hydropower bases of China (left figure) and Case study of this paper: Jinsha base with twelve cascaded plants (right figure)

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Integrated forecast and reservoir management: the Inform System

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Abstract:

Northern California climate, weather, and hydrology exhibit large variability across several temporal scales from decadal to hourly. At the same time, the region's water resources are expected to support multiple water uses (i.e., water supply, flood control, power generation, and environmental sustainability) as dependably as possible. This disparity between system inputs and requirements can only be reconciled through the existence and proper management of reservoir storage. Toward increasing reservoir utilization efficiency using real-time ensemble forecasts, a demonstration project was designed and is being executed (2002 – present) (e.g., *Georgakakos et al. 2005; HRC-GWRI, 2007*). The INFORM project develops methodologies for integrating forecasting and decision science in order to buffer the effects of climate variability and reduce water use vulnerability (for example, 2008 had almost half the reservoir system water supply deliveries of 2006). The project is implemented in close cooperation with operational forecasting and management agencies.

Adaptive management is a key aspect of the INFORM system design as is the explicit accounting of prediction uncertainty in all components – including weather patterns and precipitation, hydrological states, reservoir inflow and reservoir management. Links to the NOAA National Centers of Environmental Prediction provide real-time large-scale ensemble forecasts of upper air and surface atmospheric variables that feed mesoscale dynamic models of the atmosphere and the land-surface to produce downscaled ensemble predictions of reservoir inflow. A real-time link to the National Weather Service California-Nevada River Forecast Center (CNRFC) aligns daily the INFORM hydrologic model states to those of the operational models of CNRFC accounting for forecaster adjustments. The ensemble reservoir inflow predictions feed the decision component that provides risk-based operational trade-offs between reservoir management objectives such as flood control, water supply, water conservation, hydroelectric energy production, and environmental protection for the large reservoirs of Northern California for the range of time scales from 6 hours to 9 months.

Sample demonstration run results for 2006, 2007 and 2008 are shown at the top of Fig. 1. The columns show aggregate storage estimates in thousand acre feet (TAF) for all reservoirs in Northern California. Shown are *(a)* the initial storage at the beginning of each year (input on March 1st of each

year), and *(b)* two final storages after 9 months: the final storage at the end of each year with current practice, and the final storage at the end of each year using the adaptive INFORM system. The final reservoir storage indicates that INFORM allows for very significant water conservation for the transitional Year 2007 while it saves a bit more than actual for the very dry Year 2008 and releases more than actual in the very wet Year 2006.

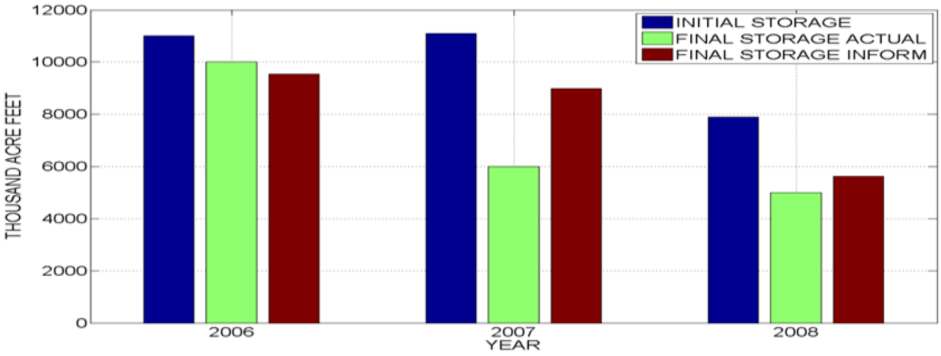

Figure 1: Results from operational demonstration of INFORM for Years 2006, 2007 and 2008

Keywords: Ensemble forecasting, reservoir management, water resources, risk-based decision support

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Verification of clustering methods applied to hydrological ensemble forecasts

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Abstract:

More and more agencies are performing flood forecasts based on precipitation forecasts from meteorological ensemble prediction systems (EPS). These can be used as input for hydrological or hydraulic models to give probabilistic discharge forecasts, with the aim of quantifying at least partly the uncertainty in the model precipitation forecasts.

It is not always practical to use all ensemble members as input, especially when a detailed hydraulic model is concerned. Limitations on computing power may force agencies to restrict the ensemble and select only a number of members, retaining a smaller sub-ensemble. Ideally, this sub-ensemble retains some of the the quantative uncertainty, and contains the most "representative" ensemble members. Clustering methods are a way of constructing such a sub-ensemble, with "representativeness" defined according to the needs end users.

Clustering is an unsupervised learning technique that divides multivariate datasets into groups based on similarity. Once the clusters are formed, every cluster can be represented by one representative member. Many different clustering algorithms and methods to select the representative member in each cluster exist.

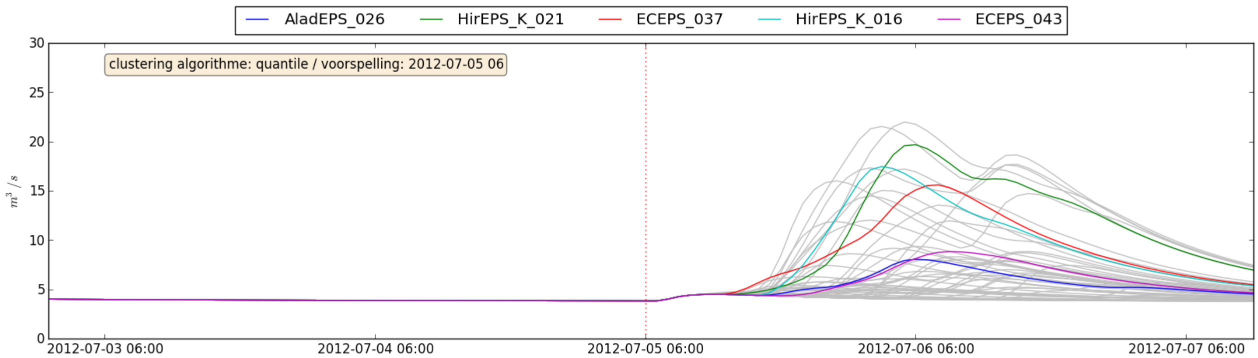
Here, we present results of a study that was performed at the Royal Meteorlogical Institute of Belgium (RMI) in collaboration with International Marine and Dredging Consultants (IMDC) for the Vlaamse Milieumaatschappij (VMM). VMM is the agency responsible for water management of non-navigable rivers in Flanders, for which they have very detailed hydrological and hydraulic models.

We test several clustering methods, used to select 5-10 representative members from the ECMWF Ensemble Prediction System (ENS) and Grand Limited Area Model Ensemble Prediction System (GLAMEPS). Our tests focus on the Dijle catchment in Belgium, for two periods in 2012 with high discharge, a winter and a summer case. We use only accumulated precipitation at different lead times as "clustering variable". Some implemented methods that give promising results include a agglomerative hierarchical clustering method (e.g. Marsigli et al., 2005) and our own "optimum distance method" (similar to the Sattler and Feddersen, 2005), which aims to select the ensemble

members that are the most different from each other. We also include a simple method making use of quantiles of the total accumulated precipitation.

Using observed precipitation, we give verification results, comparing precipitation forecasts from the whole ensemble with those of the generated smaller sub-ensembles. We also use these ensembles as input for a hydrological model, and look at the impact of the clustering methods on the discharge forecasts.

In the figure below, we show one example. The discharge forecasts resulting from the full GLAMEPS ensemble are shown in grey, and the members selected by the quantile clustering method in color.



Keywords: Hydrological ensemble forecasting, Clustering algorithms, Verification

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Sequential streamflow assimilation for short-term hydrological ensemble forecasting

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Abstract:

Data assimilation holds considerable potential for improving hydrologic predictions as demonstrated in numerous studies. Because hydrological models are imperfect, hydrologists need to continuously update the state variables of their model in order to adapt to day to day situations. This project examines the application of the ensemble Kalman filter (EnKF) for streamflow assimilation within an ensemble prediction system designed for short-term hydrological forecasting at the outlet of the au Saumon watershed. Soil moisture in the intermediate layer, soil moisture in the deep layer, and land flow are thus updated using sequential data assimilation technique (EnKF) with 50 ensemble members based on observed runoff in a real-time mode. Such assimilation aims providing optimized initial states which can be used as initial conditions for flood forecasts. The case study is set on the 767 km2 Saumon catchment (Québec-Canada). To the authors knowledge, this is the first EnKF implementation for the operational distributed model Hydrotel, which is used for a variety of applications including real time flood forecasting, using meteorological forecasts, and the estimation of hydrological effects resulting from changes in the physical characteristics of a basin. EnKF results show a substantial improvement in performance and reliability over an implementation without assimilation. Manual assimilation was also assessed and led to a performance similar to that of EnKF using the ensemble mean; however, the EnKF forecasts are more reliable. While an ensemble size of 1000 was required to fully sample the hydrological and meteorological uncertainty, similar results were obtained in terms of skill when limiting the ensemble size to 50 members.

Keywords: Ensemble streamflow forecasting; Streamflow assimilation; Ensemble Kalman filter; Performance; Reliability; Economic value

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A flood inundation climatology at continental scale

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Abstract:

To date there is no coherent and consistent database on observed or simulated flood event inundation and magnitude at large scales (continental to global). The only compiled data set showing a consistent history of flood inundation area and extent at a near global scale is provided by the MODIS-based flood maps. Here, we present for the first time a proof-of-concept study in which we employ a computationally efficient 2-D hydrodynamic model (LISFLOOD-FP) complemented with a sub-grid channel formulation to generate a complete flood inundation climatology of the past 40 years (1973-2012) for the entire Australian continent at 1 km resolution. Our proof-of-concept study will serve as a demonstrator case that this type of model setup can be employed to reliably simulate past flood events with reasonable accuracies both in time and space for the entire globe. We will present complete simulations results and analysis for the Murray-Darling basin (>1 million square km in size).

Keywords: Flood inundation, floodplain storage, modeling, climatology, remote sensing

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Determining and communicating the uncertainty of event-based, areal precipitation

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Abstract:

A data set of 1800, 12-hour precipitation events from 2005-2013 was collected to assess the areal precipitation distributions across a 73,000 square kilometre area in eastern Oklahoma and northwest Arkansas. The data were collected on a 4 km grid, yielding 4578 proxy precipitation gages for each event. Examination of the event-based, areal precipitation amounts indicated they closely followed gamma distributions that used the observed mean areal precipitation. Computed probabilities of exceedance (POE) from the data were compared to gamma approximations. For the 10% POE, the mean absolute errors (MAEs) were just under 4%. At the 25% probability of exceedance, the mean absolute errors were just over 4%. Summary data and analyses will be presented along with several individual cases.

The data imply that a reasonable forecast of areal mean precipitation for an event allows one to estimate the actual probability distribution of rainfall amounts for the event and provide calculable uncertainties for select precipitation amounts. This ability to downscale the expected mean areal precipitation to near-point resolution (4km x 4km) facilitates communicating important decision making information on small scales, e.g., small watersheds, recreational areas, urban areas and other flash flood susceptible locations.

An interactive, user-friendly interface for decision makers to use to assess the likelihood of selected precipitation amounts for various time periods will be shown.

Keywords: Precipitation Distributions, Probablity of Exceedance, Probabilistic Quantitative Precipitation Forecasts

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Assimilation of satellite quantitative precipitation estimates and streamflow into distributed hydrologic models for flood prediction

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Abstracts:

The launch of the Global Precipitation Measurement (GPM) core satellite in 2014, and associated ground processing system enhancements, are expected to greatly improve the accuracy and latency of satellite quantitative precipitation estimates (QPEs) and thereby enhance their potential utility in flood forecasting. In this work, we conduct experiments to examine the accuracy of flood prediction when satellite precipitation estimates and streamflow observations are assimilated into the distributed Sacramento Soil Moisture Accounting (SAC-SMA) model, via a variational data assimilation (DA) framework. The DA technique, developed at Office of Hydrologic Development, National Weather Service, estimates hourly-varying mean field bias in the precipitation data and assimilates flow observations at basin outlet as well as interior locations. These experiments are performed for a headwater catchment in Missouri using hourly Climate Prediction Center Morphing (CMORPH) QPEs at the HRAP scale (~16 km^2) as the forcing to the distributed SAC-SMA. The CMORPH is functionally similar to planned GPM precipitation products. The performance of DA using CMORPH QPEs is comparatively evaluated with model predictions based on NWS operational multisensor QPE. The results of the experiments indicate that a) CMORPH data exhibit significant positive bias at this location, which led to overprediction of discharge during flood events; b) streamflow assimilation greatly mitigates the bias in the streamflow analysis within the assimilation window; and c) the adjustment to the bias of CMORPH is limited by DA - the bias appears to be compensated by over-adjustment of soil moisture.

Keywords: Data assimilation, satellite precipitation, flood prediction

Ensemble data assimilation for operational water quality forecasting

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Abstract:

Due to large dimensionality of the state vector and sparsity of observations, the initial conditions (IC) of watershed water quality models are subject to large uncertainties. To improve forecast accuracy and to quantify uncertainty in the ICs, an ensemble data assimilation (DA) procedure has been developed for the Hydrologic Simulation Program – Fortran (HSPF). To utilize all available hydrologic and water quality observations, it is important that the DA technique be able to handle strong nonlinearity in hydrologic and biochemical observation equations in addition to nonlinear model dynamics. The procedure, which is being implemented for operational use at the Water Quality Control Center of the National Institute of Environmental Research in Korea, uses maximum likelihood ensemble filter (MLEF) which combines strengths of variational assimilation (VAR) and ensemble Kalman filter (EnKF). The observations assimilated are water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonium (NH_4), nitrate (NO_3), phosphate (PO_4), chlorophyll a (CHL-a) and streamflow. In this presentation, we describe the procedure, identify challenges, share single-valued and ensemble verification results and illustrate how the procedure may be used in operational ensemble water quality forecasting.

Keywords: ensemble data assimilation, water quality, ensemble forecasting

Operational implementation of the Hydrological Ensemble Forecast Service (HEFS)

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Abstract:

The Hydrologic Ensemble Forecast Service (HEFS) is an operational forecasting system that quantifies the total uncertainty in hydrologic forecasts, including the uncertainties contributed by the meteorological forcing and the hydrologic modeling. The HEFS is a modular system that includes software tools for quantifying the different sources of uncertainty and for conducting retrospective forecasting (hindcasting) and verification. The HEFS leverages weather and climate forecasts to produce ensemble forecasts of precipitation, temperature and streamflow (among other variables) at forecast lead times ranging from one hour to one year.

The HEFS is being implemented in two phases, the first of which initially supported use at a limited number of National Weather Service (NWS) River Forecast Centers (RFCs), together with limited validation of the forcing and streamflow forecasts. The second phase will provide a template for a reliable and consistent implementation at all RFCs, informed by the first phase of implementation. The physical rollout of the HEFS (distribution, training and support of the software) will be extended to the remaining (eight) RFCs. It is anticipated that each RFC will implement the HEFS in a gradual and coordinated way, beginning with a limited number of locations. The vision is for the HEFS to become fully integrated into the CHPS baseline and routine operations of all RFCs (at selected locations) within the timeframe of the HEFS rollout. This contribution describes the operational implementation of the HEFS, including the main lessons learned from the first phase of implementation and the early use of the HEFS.

Keywords: HEFS, hydrologic ensemble forecasts, RFC

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