OPERATIONAL IMPLEMENTATION OF THE HYDROLOGICAL ENSEMBLE FORECAST SERVICE (HEFS)

Mark Fresch[1], James D. Brown[2], and Ernie Wells[3]

[1] Office of Hydrologic Development, National Weather Service, NOAA, Silver Spring, Maryland
[2] Hydrologic Solutions Limited, Southampton, United Kingdom
[3] Office of Climate, Water, and Weather Services, National Weather Service, NOAA, Silver Spring, Maryland

HEPEX 10th Annual Workshop
College Park, MD June 2014

Abstract

The National Weather Service's (NWS) 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 focused on a limited number of 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. The plan is 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 routine operations of all RFCs (at limited locations) within the timeframe of the HEFS rollout (CY 2014). 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.

First phase of implementation

Since 2011, the HEFS has transitioned from a collection of prototype components into a service integrated into the NWS RFC operational streamflow forecast system, the Community Hydrologic Prediction System (CHPS). Figure 1 shows a schematic of the HEFS components and data flows; see Demargne et al. (2014) for a description of the components. In mid-2012, the HEFS was provided to five NWS RFCs. Since then, those RFCs have been using the HEFS daily at an increasing number of forecast locations. At the Middle Atlantic and Northeast RFCs, the locations include points within the New York City (NYC) water supply. In parallel, the NWS Office of Hydrologic Development (OHD) has improved the HEFS software, and developed training and documentation, with feedback from the RFCs. In addition, limited validation of the forcing and streamflow forecasts has been accomplished (see Brown et al., 2013, Brown et al., 2014a/b/c, and associated reports available at the bottom of http://www.nws.noaa.gov/oh/hrl/general/indexdoc.htm).

Second phase of implementation

In late 2014, the HEFS will be provided to the remaining NWS RFCs. During this second phase, the strategy is to expand the HEFS in a gradual and coordinated way, along with training, support, and additional validation. A gradual approach is necessary to monitor the implementation, manage expectations, develop products and services that meet the needs of the RFCs and their customers, and to ensure that the rollout is reinforced by ongoing validation and testing. The initial coverage will focus on headwater locations and then expand, as the RFCs gain experience with the HEFS, including additional validation at newly implemented locations. Meanwhile, NWS will continue to address HEFS issues and constraints, and take steps to make the HEFS forecasts and forecast products more widely available.

At the beginning of the second phase, training and guidance will be provided on the science and use of the HEFS. The HEFS software and documentation (user's manuals and implementation guides) will be provided to the RFCs. The RFCs will begin by implementing the HEFS at two locations on a CHPS local development and test environment. The implementation includes calibration of the HEFS components and adding those component to the RFC automated or semi-automated runs of hydrological models within the CHPS, also known as workflows. The HEFS calibration tools are GUI-based and include graphics images for quality control. This limited implementation will allow the RFCs to familiarize themselves with the HEFS and adjust the HEFS-CHPS workflows, as appropriate, for accuracy and for RFC needs. Then, a second round of training will be provided on hindcasting (i.e. retrospective forecasting with historical forcing data) and verification. Both training sessions are planned to be repeated annually for additional RFC staff, as needed.

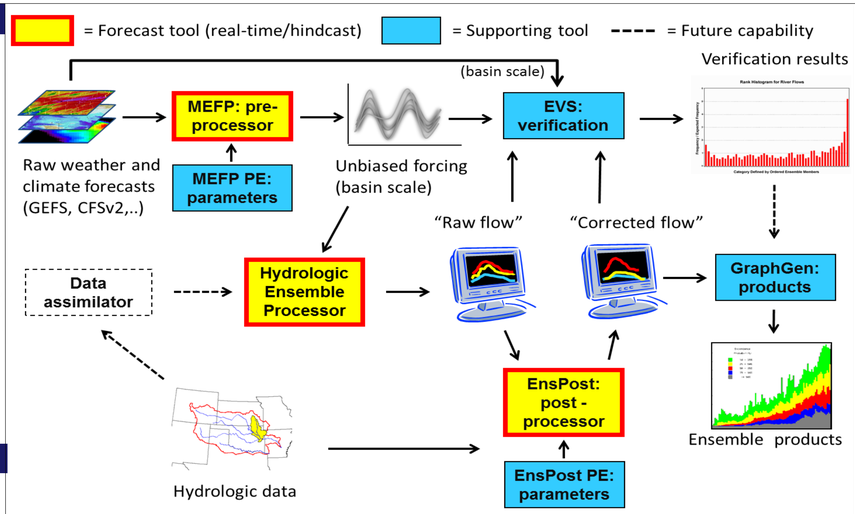

Fig. 1. Schematic view of the HEFS in the CHPS. The GEFS and CFSv2 are the Global Ensemble Forecasts System and Climate Forecast Systems Version 2. The MEFP is the Meteorological Ensemble Forecast Processor, which accounts for the meteorological uncertainties in the raw forcing and corrects for biases. The EnsPost is the Ensemble Post-processor, which accounts for the hydrologic uncertainties and corrects for hydrologic biases. The EVS is the Ensemble Verification Service, which is used to evaluate forcing and streamflow hindcasts. The MEFP and the EnsPost both require parameter estimators (PEs). The Graphics Generator (GraphGen) is a GUI-based graphical image builder and editor.

After the second round of training, the RFCs will begin to expand their coverage of the HEFS, guided by validation through hindcasting and verification. By this point, OHD plans to provide a fix to one high priority science issue, namely a low (dry) bias in the probability of precipitation and light precipitation forecasts by the MEFP. Initially, the HEFS forecasts will be used internally by the RFCs until they have undergone some level of validation, at which point they will be distributed publically.

The OHD plans to help the RFCs conduct hindcasting and verification of the HEFS. For example, templates of verification products will be provided to ensure a consistent application of hindcasting and validation across RFC domains, together with expert guidance and training of RFC staff. In addition, under the auspices of the new National Water Center in Tuscaloosa, Alabama, a data archiving service is being developed alongside a Water Resources Evaluation Service to support routine hindcasting and validation of the HEFS and other forecasting systems. An ongoing concern has been the computing resources required for extensive hindcasting. However, OHD has made advances in reducing the hindcast run-times. In addition, OHD has developed a tool for automating hindcasting runs and conducting basic quality control checks. Finally, cloud computing is being explored as a resource for more comprehensive HEFS hindcasting and validation.

Operational support of the HEFS has been ongoing since the first phase of implementation and allows users to provide feedback, report bugs and request assistance on specific issues. This support takes advantage of existing reporting mechanisms, such as issue tracking software. Primary support for all RFC issues is handled by the Hydrologic Support Branch (HSB) of the NWS's Office of Climate, Water, and Weather Services (OCWWS). During the initial phase of implementation, the HSB typically distributed requests for help on HEFS issues to technical experts. The HSB staff are also attending training, and they will gradually provide tiered support of the HEFS, as their level of experience and knowledge increases.

During the beginning of this second phase of implementation, a limited number of HEFS products will be made available to the public. Training and outreach on HEFS products (and possibly theory) will be needed by the NWS Weather Forecasts Offices and other stakeholders.

The OHD plans to develop an introduction to the HEFS in both web-based and seminar forms, together with guidance on the HEFS products. The HEFS products will eventually link to web-based explanations, and the seminars will be available to the RFCs for outreach to the WFOs and other stakeholders.

Following the second phase of implementation, the operational version of the HEFS will remain relatively stable (frozen), with ongoing science developments planned for a future operational version. There are two main reasons to limit the changes to the operational HEFS. One reason is to enable the creation of a set of hindcasts that accurately represent the quality of the operational version of the HEFS for at least 2 years. These hindcasts will be used by the RFCs, OHD, and their partners, such as the NYC Department of Environmental Protection (NYCDEP). A second reason for freezing the operational HEFS is to minimize the need for RFCs' recalibration of the MEFP and the EnsPost. Within this context, fixes or changes to the HEFS to improve forecasting procedures or products, but do not significantly impact the forecasts, will be ongoing.

Future

Eventually, forecasts from the HEFS will be integrated into the warning/hazard services at the WFOs. For example, flood warnings may be calibrated against the forecast probabilities of flooding provided by the HEFS, rather than the RFC single-valued forecasts. As the HEFS forecasts become more widely available, differences will arise between the probabilistic and single-valued forecasts (e.g. single-valued forecasts falling outside of the nominal HEFS range) due to the different forcing data, among other reasons, for which guidance will be required.

In parallel to these developments in products and services, scientific enhancements will be prioritized and implemented in a research version of the HEFS (for subsequent operational implementation). Several research and development priorities have been identified through the recent validation work and earlier studies. For example, the EnsPost and other statistical techniques are heavily reliant on historical data and their associated requirements for stable distributions and sensitivities to sample size (e.g. for extreme events). In this context, data assimilation would improve both the single-valued and ensemble forecasts and better account for the hydrologic uncertainties and biases, while being less dependent on historical data for calibration. Elsewhere, the MEFP will be evaluated and improved for predicting under extreme conditions (e.g. extreme droughts and floods). A comprehensive science plan is being developed to address these and other limitations of the HEFS.

References and Acknowledgements

References

Brown, J.D., Wu, L., He, M., Regonda, S., Lee, H. and Seo, D-J. 2014a: Verification of temperature, precipitation and streamflow forecasts from the NOAA/NWS Hydrologic Ensemble Forecast Service (HEFS). 1. Experimental design and forcing verification. *Journal of Hydrology*, in press.

Brown, J.D., He, M., Regonda, S., Wu, L., Lee, H. and Seo, D-J. 2014b: Verification of temperature, precipitation and streamflow forecasts from the NOAA/NWS Hydrologic Ensemble Forecast Service (HEFS). 2. Streamflow verification. *Journal of Hydrology*, in press.

Brown, J.D. 2014c: Verification of temperature, precipitation and streamflow forecasts from the Hydrologic Ensemble Forecast Service (HEFS) of the U.S. National Weather Service: an evaluation of the medium-range forecasts with forcing inputs from NCEP's Global Ensemble Forecast System (GEFS) and a comparison to the frozen version of NCEP's Global Forecast System (GFS). Technical Report prepared by Hydrologic Solutions Limited for the U.S. National Weather Service, Office of Hydrologic Development, 139pp.

Brown, J.D. (2013) Verification of long-range temperature, precipitation and streamflow forecasts from the Hydrologic Ensemble Forecast Service (HEFS) of the U.S. National Weather Service. Technical Report prepared by Hydrologic Solutions Limited for the U.S. National Weather Service, Office of Hydrologic Development, 128pp.

Demargne,J., Wu, L., Regonda, S., Brown, J., Lee, H., He, M., Seo, D.J., Hartman, R., Herr, H., Fresch, M., Schaake, J., and Zhu, Y. 2014 The Science of NOAA's Operational Hydrologic Ensemble Forecast Service. *Bull. Amer. Meteor. Soc.*, **95**, 79-98.

Acknowledgments

The authors thank Lee Cajina, Hank Herr, Jon Roe, Rob Hartman, Limin Wu, John Schaake, Julie Demargne, Dong-Jun Seo, Eric Jones, John Lhotak, Brett Whitin, Ned Pryor, and Erick Boehmler.

The views expressed herein are those of the authors and do not necessarily reflect the position of the National Weather Service.