National Weather Service (NWS) Hydrologic Ensemble Forecast Service (HEFS)

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NCEP Workshop August 2019

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Outline

- Impetus for Hydrologic Ensemble Forecasts
- HEFS Concept and Design
- Implementation Status and Validation
- Products and Services
- Next steps and Challenges

Why use hydrologic ensemble forecasts?

National Research Council, 2006

"All prediction is inherently uncertain and effective communication of uncertainty information in weather, seasonal climate, and hydrological forecasts benefits users' decisions. These uncertainties generally increase with forecast lead time and vary with weather situation and location. *Uncertainty is thus a fundamental characteristic of weather, seasonal climate, and hydrological prediction, and no forecast is complete without a description of its uncertainty.*" [emphasis added]

COMPLETING THE FORECAST

Characterizing and communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts

Committee on Estimating and Communicating Uncertainty in Weather and Climate Forecasts

Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

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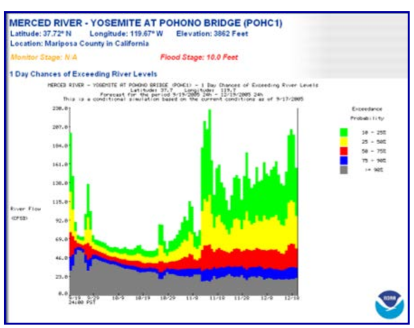
Why use hydrologic ensemble forecasts?

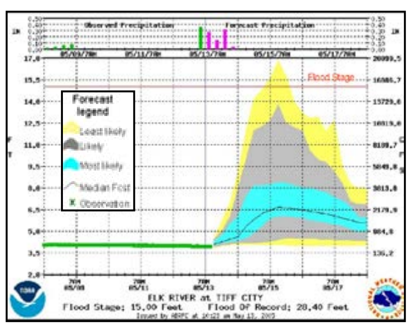
- Consistent feedback from customers and research community
  - 2006 National Research Council (NRC) report
  - 2008 Customer Feedback Insights (CFI) survey
  - River Basin Commission Stakeholder Engagements and Regional Water Conversations
- Aptima study (human centered engineering) validated need for water managers
- Multiple Internal NWS Service Assessments
  - Red River Floods in 1997 and 2009
  - Central U.S. Floods in 2008
  - Nashville Flooding in 2010

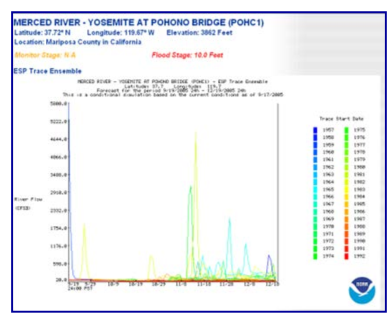
HEFS Service Level Objectives

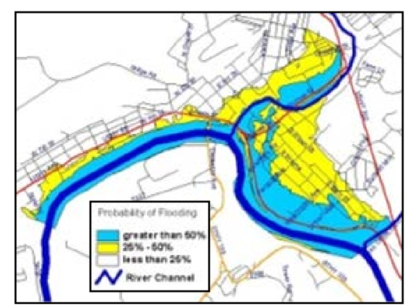
Produce ensemble streamflow forecasts that:

- seamlessly span lead times from one hour to one year
- statistically calibrated (unbiased with reliable spread)
- consistent across time and space
- effectively capture information in NWS weather/climate models
- dependable (consistent with retrospective forecasts)
- adequately verified
- aid user's decisions (compatible with Decision Support Systems)









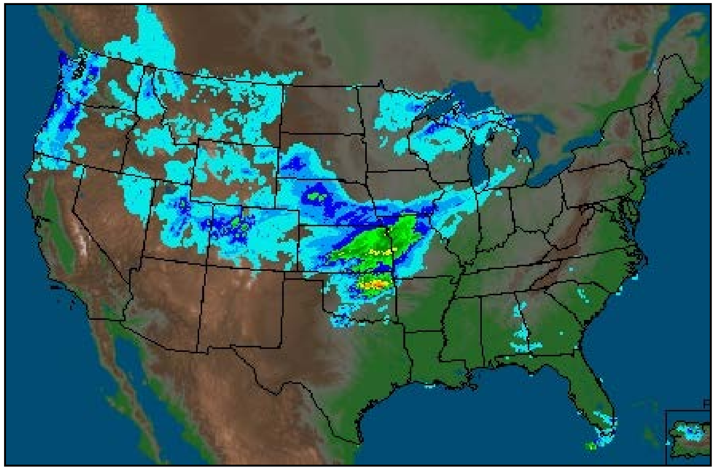
Hydrologic Ensemble Forecast Service (HEFS)

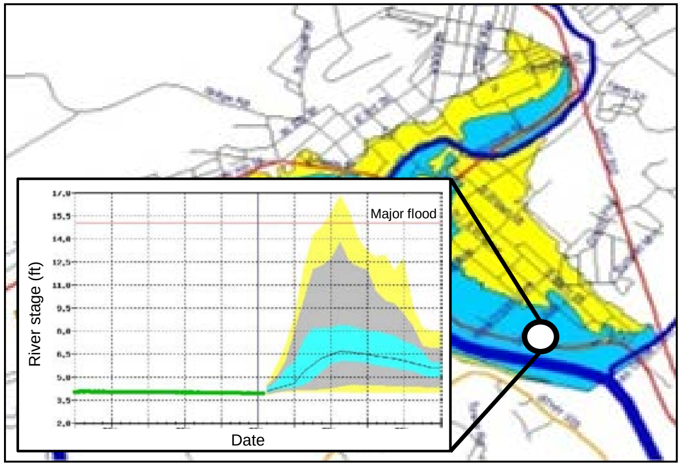
Goal: enhance NWS hydrologic services by providing improved probabilistic information to support risk-based decisions

Feature	ESP (old service)	HEFS (new service)
Forecast time horizon	Weeks to seasons	Hours to years, depending on the input forecasts
Input forecasts (“forcing”)	Historical climate data (i.e. weather observations) with some variations between RFCs	Short-, medium- and long-range weather forecasts
Uncertainty modeling	Climate-based. No accounting for hydrologic uncertainty or bias. Suitable for long-range forecasting only	Captures total uncertainty and corrects for biases in forcing and flow at all forecast lead times
Products	Limited number of graphical products (focused on long-range) and verification	A wide array of data and user-tailored products are planned, including standard verification

How are the ensembles formed?

By capturing skill in weather forecasts

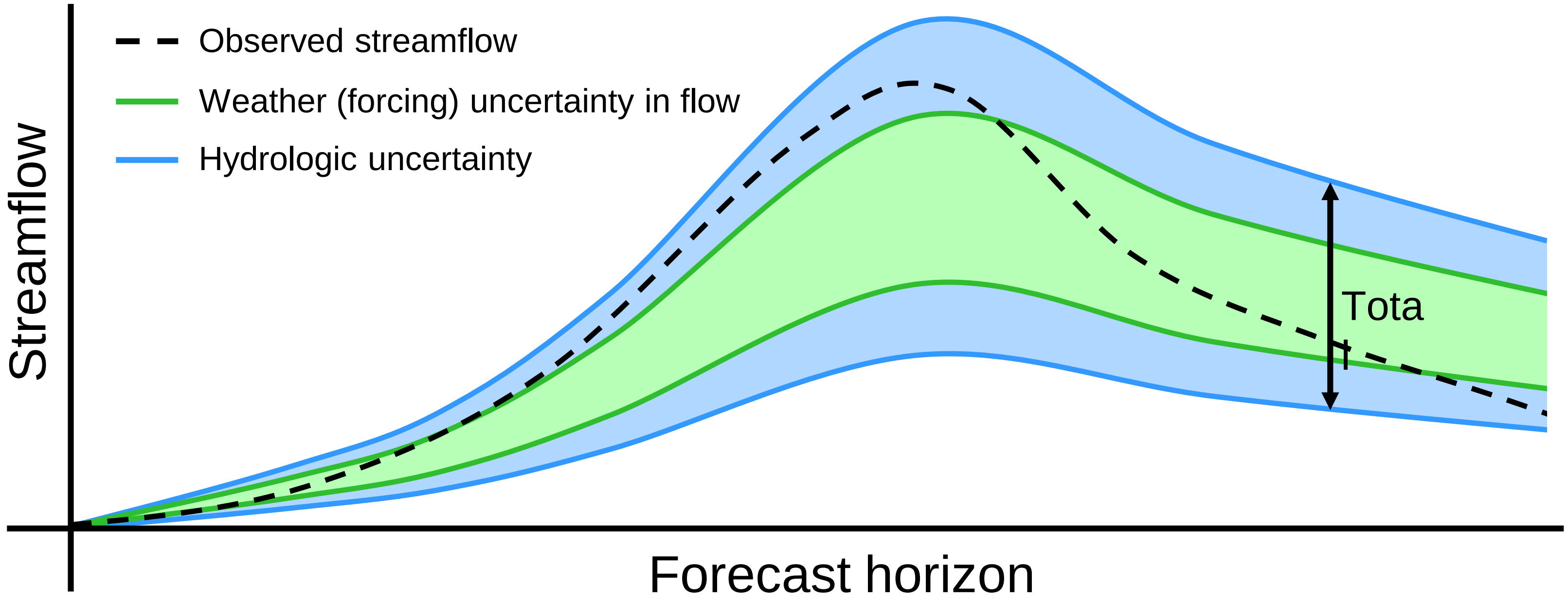




- Ensembles are standard in weather forecasting
- Include single models and “multi-model” ensembles
- Essential that water forecasts capture this information
- But, problematic to use them directly: wrong scale, biases

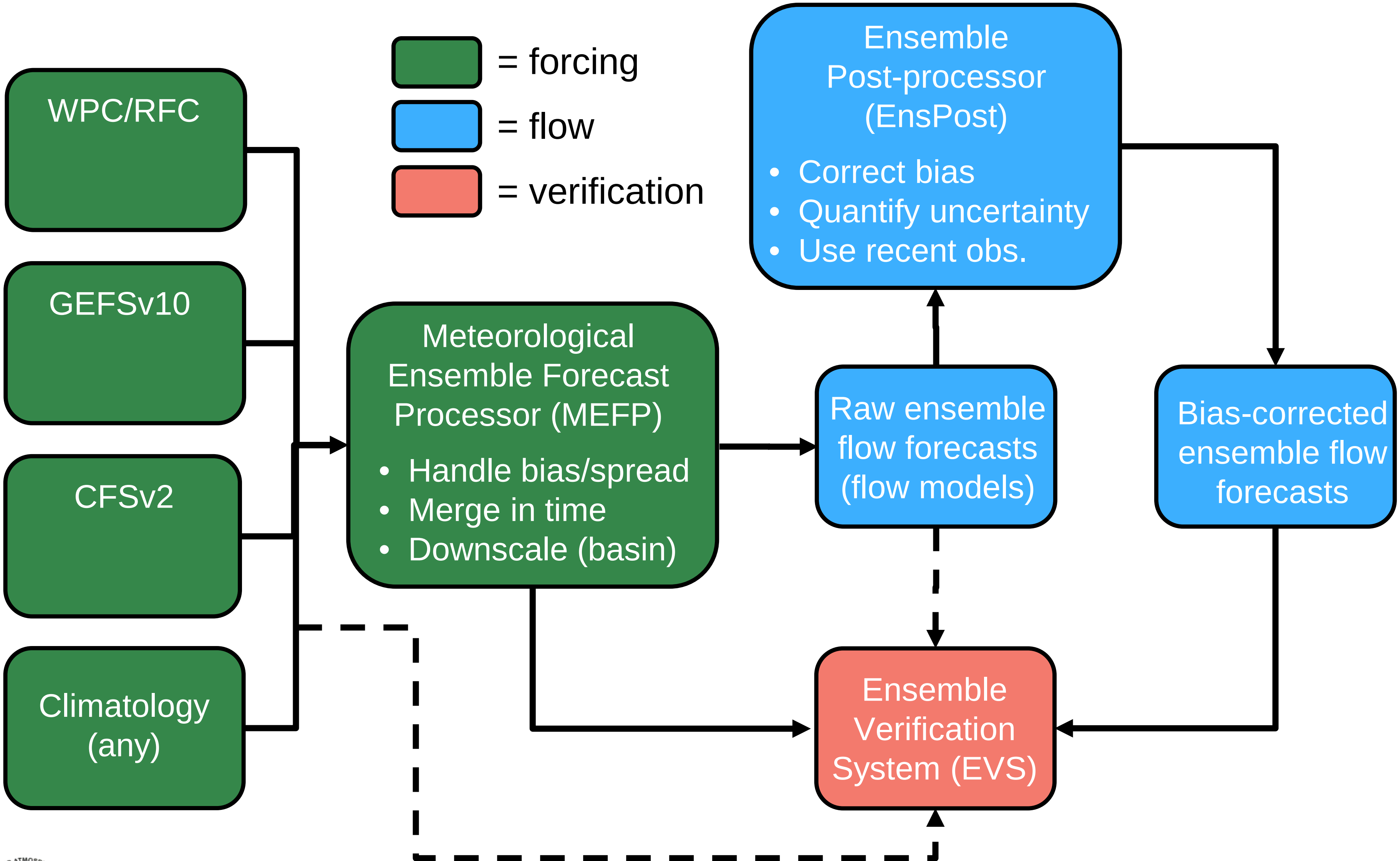
How are the ensembles formed?

By capturing hydrologic skill/uncertainty



- HEFS aims to “capture” observed flow consistently
- So, must account for total uncertainty & remove bias
- Total = forcing uncertainty + hydrologic uncertainty

HEFS workflow (inputs and outputs)



HEFS Development Timeline

- 2011: Definition of initial version
- 2012-13: Developed prototype versions and delivered training to five (Phase 1) RFCs
- 2014: Release version 1.0 to all RFCs and provided training to remaining RFCs
- 2014-15: Completed focused evaluation at selected basins in 4 RFCs demonstrating HEFS skill
- 2015-16: RFCs begin implementation at initial locations
- 2017-2019: RFCs expand implementation; OWP/RFCs accomplish Baseline Validation; OWP/RFCs develop plans to address limitations of HEFS version 1

Motivations for Baseline Validation

- **To accelerate implementation**
  - To provide targets for the public distribution of HEFS products on AHPS
- **To create a performance benchmark**
  - To provide a benchmark for future HEFS versions and other NWS services (e.g. single-valued forecast, NWM)
  - To clarify our own requirements (e.g. GEFS (re)forecasts)
- **To develop best practices for evaluation**
  - First objective, large-sample, evaluation of our hydrologic products and services

Methodology for Baseline Validation

- Streamflow forecast for 1-30 days (GEFS for 1-15, then climatology)
  - Maximizes sample size (allows for daily forecast for 30 years)

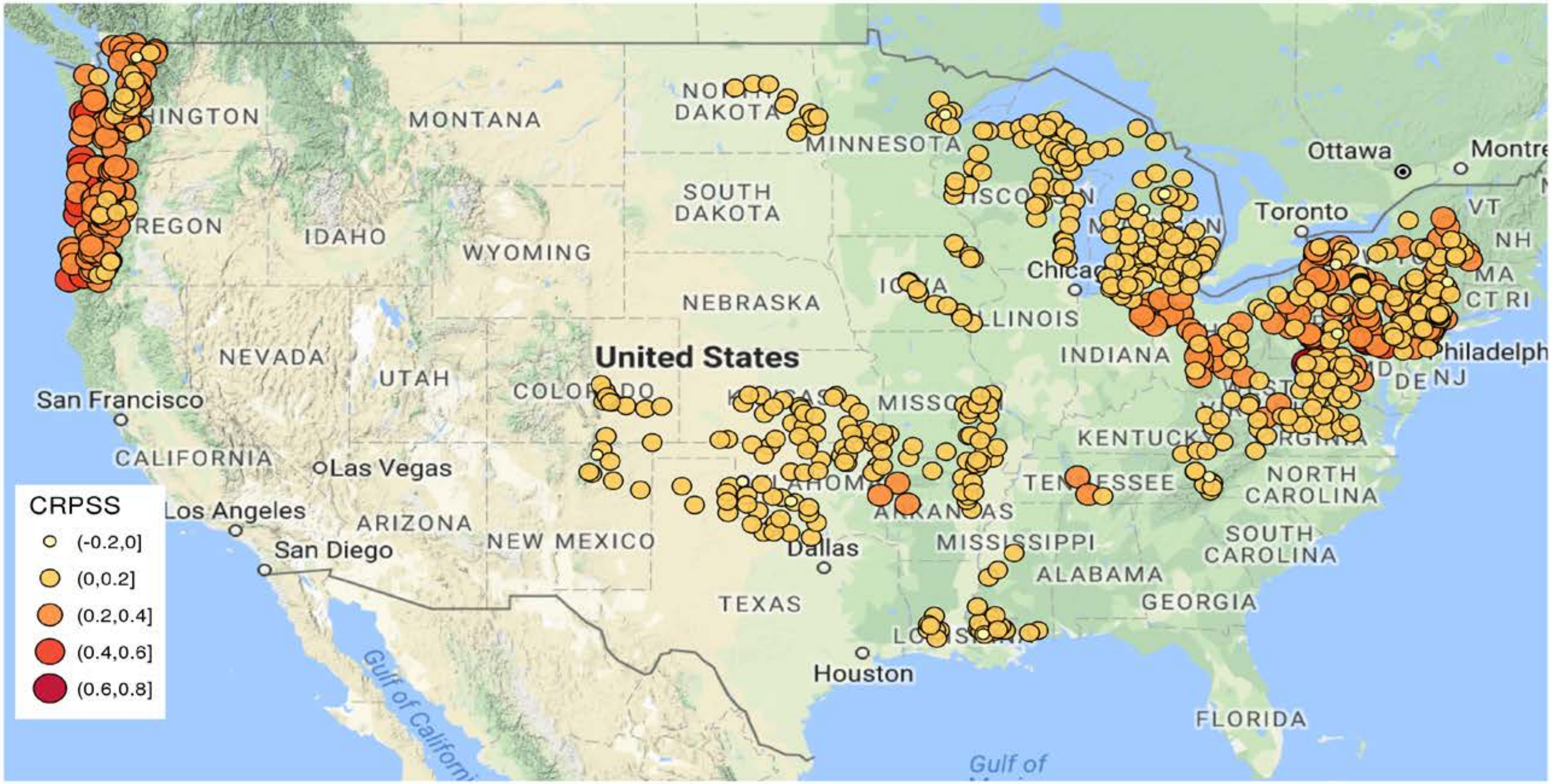
- Legacy climatological ensemble (ESP) as a baseline for skill

- Utilize multiple metrics (CRPSS, BSS, correlation coefficient, etc) to capture multi-dimensional character of forecast quality

- Precipitation and temperature, only where necessary to troubleshoot problems identified in streamflow validation

Maximum skill (CRPSS) HEFS vs. ESP

Skill everywhere, but greatest in Pacific Northwest and Northeast

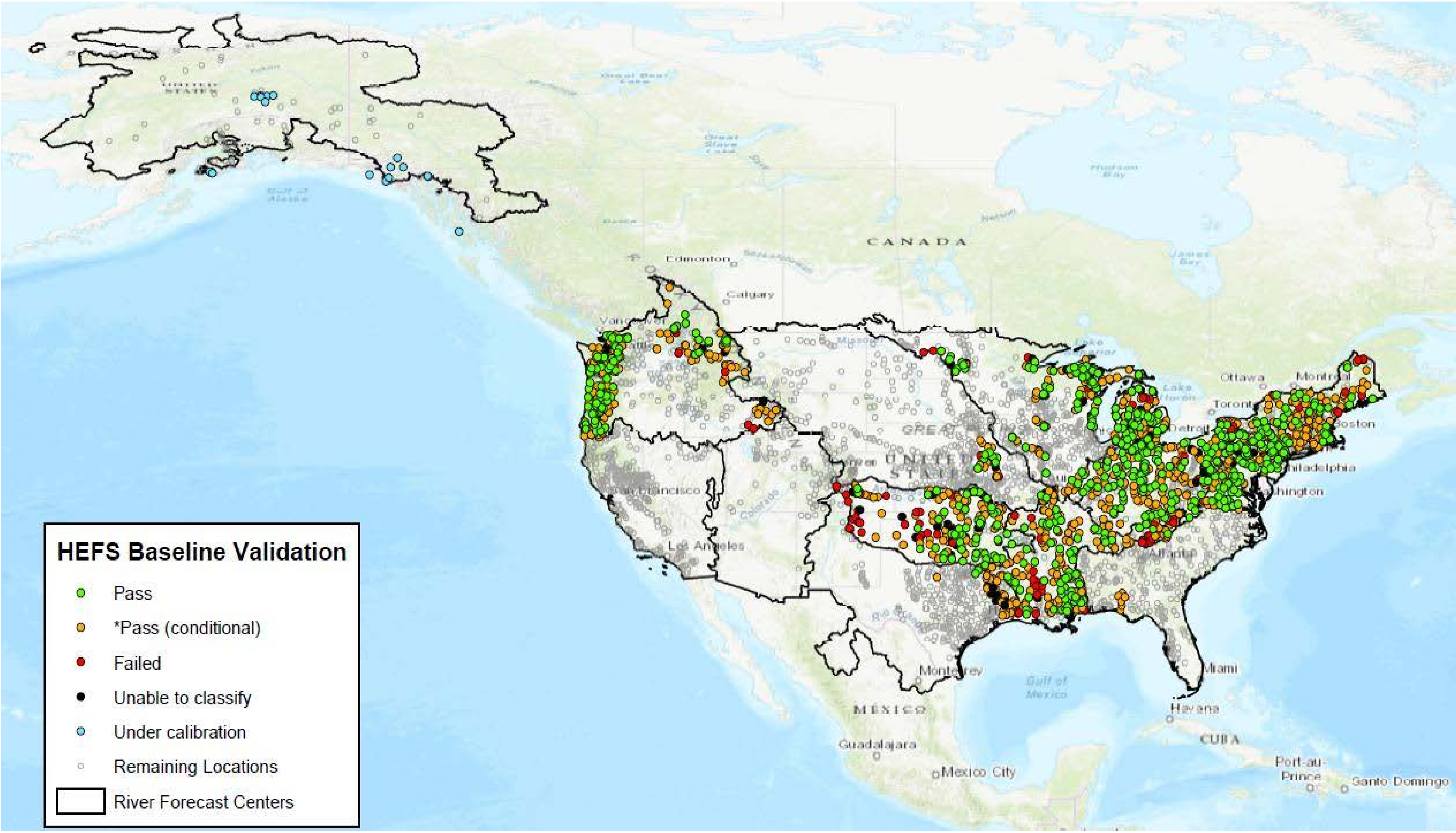


Weaker skill in central plains, partly due to lower predictability of heavy, convective precipitation

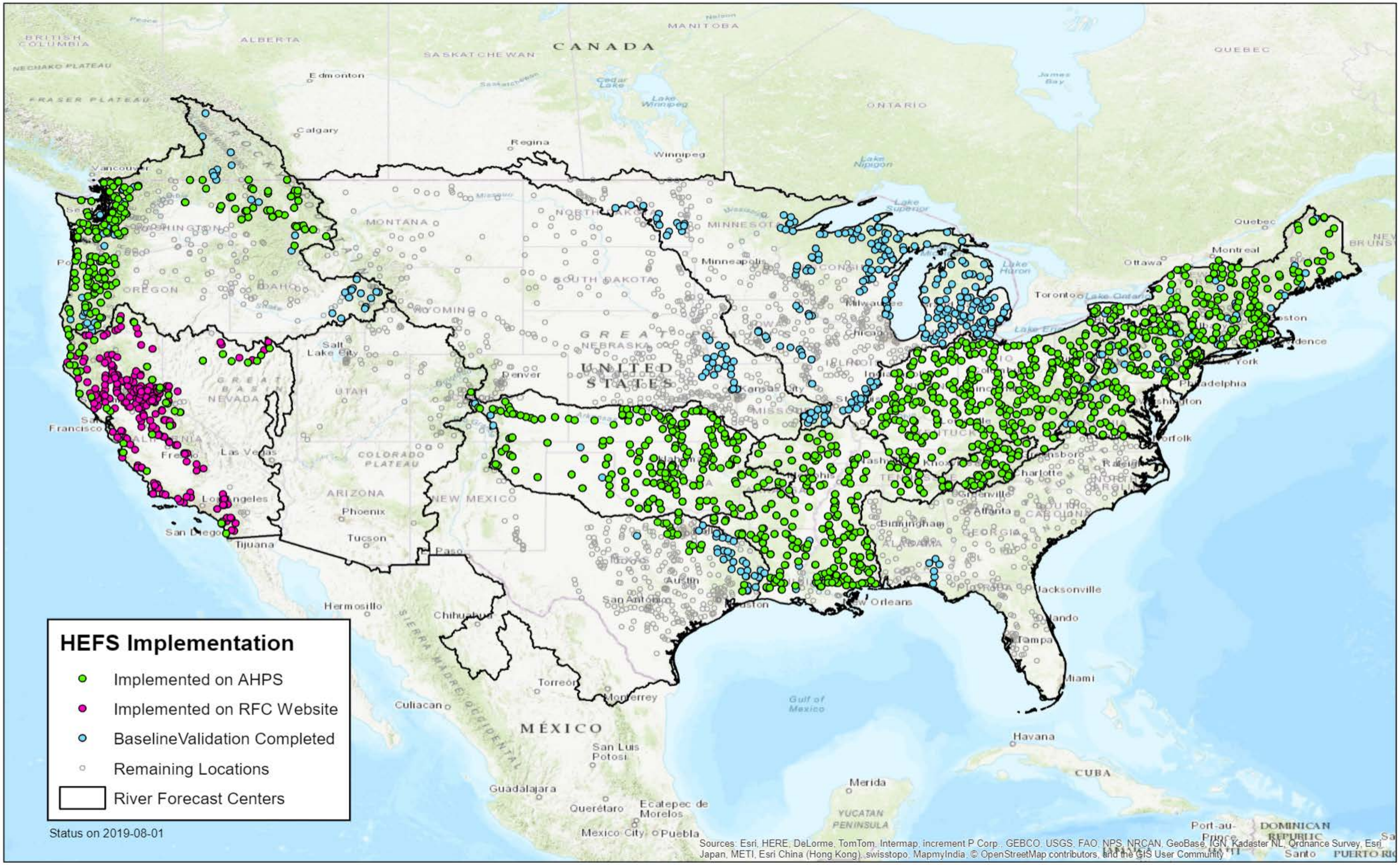
Classification of Validation Results

- **Pass**: The skill (CRPSS & BSS; relative to ESP) is consistently positive across all thresholds and lead times, good improvement in correlation and bias (notwithstanding some noise)
- **Conditional pass**: skill (relative to ESP) is mostly positive, but can be negative at some thresholds/lead times
- **Fail**: lack of skill or consistent negative skill (relative to ESP) across multiple thresholds and lead times, typically due to configuration or hydrological modeling error

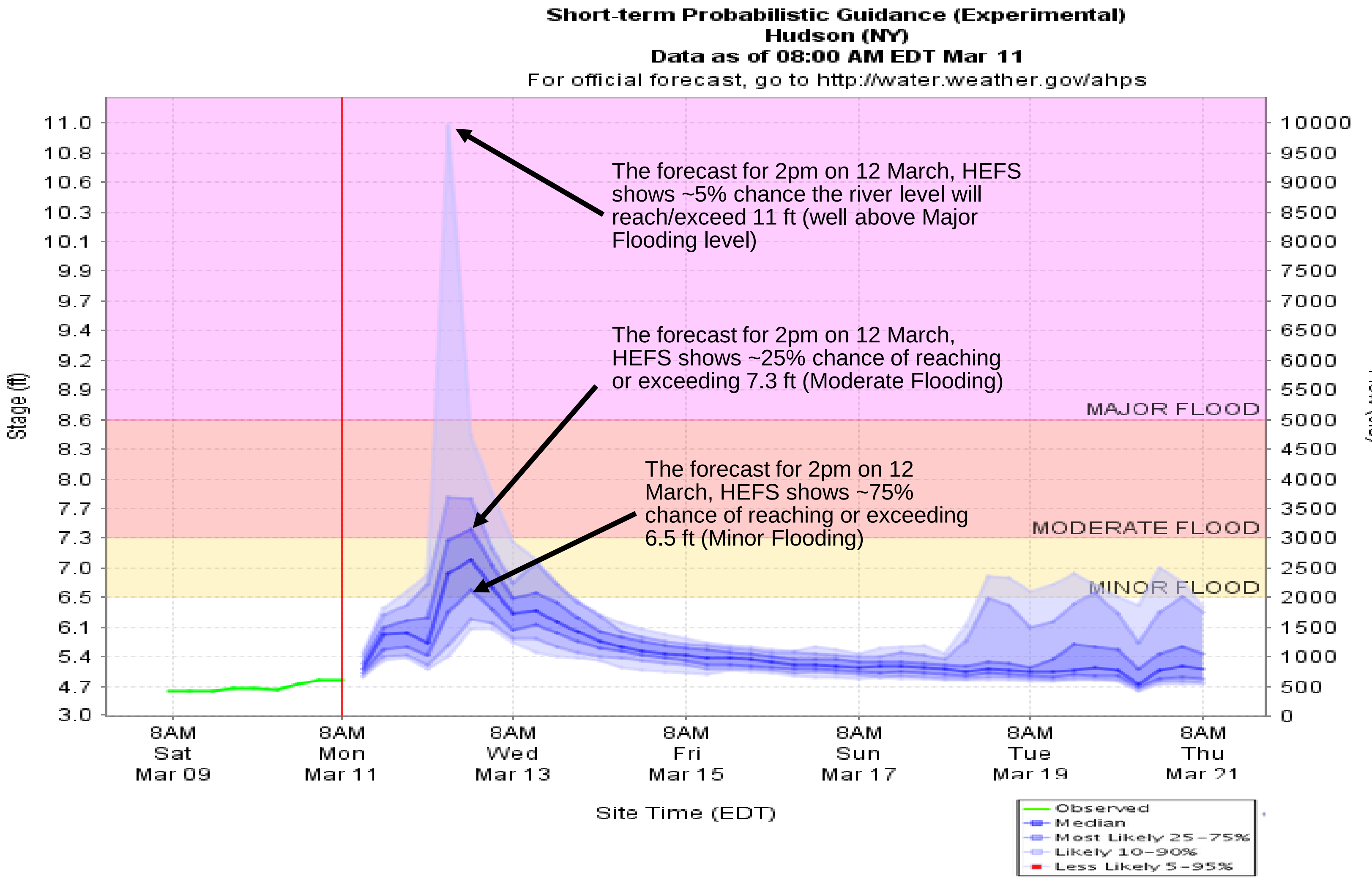
HEFS Baseline Validation Status - Aug 2019



HEFS Implementation Status



Short-range Probabilistic Product

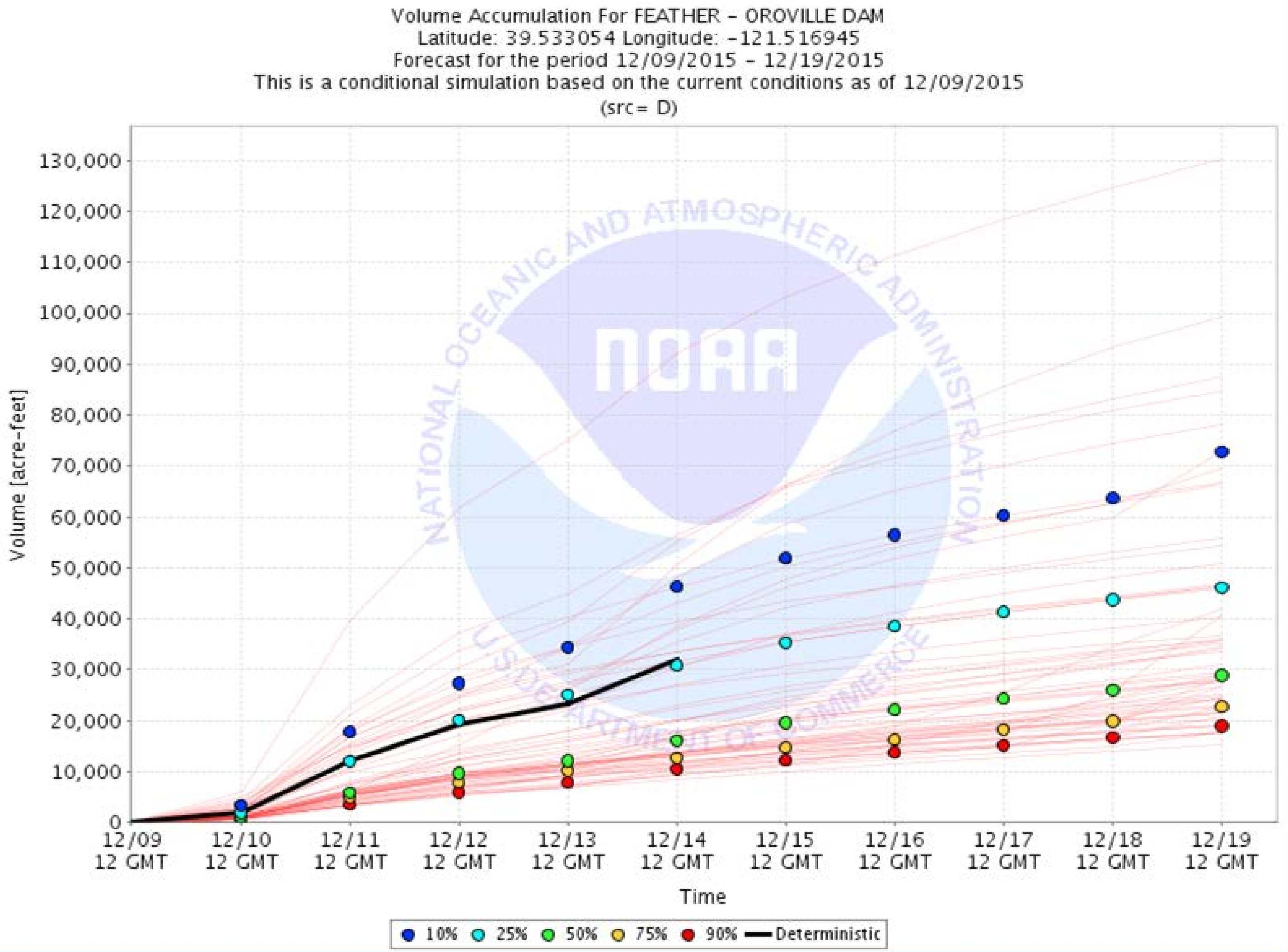


Example: 10-Day Accumulated Reservoir Inflow

Accumulated Reservoir Inflow over next 10 days

- 1 day
- 2 day, etc.

Includes single value forecast

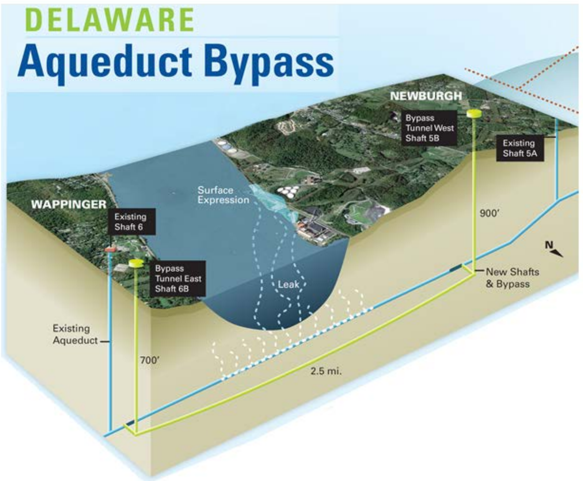


Early applications of HEFS

Managing NYC water supply

- Croton; Catskill; and Delaware
- Includes 19 reservoirs, 3 lakes; 2000 square miles
- Serves 9 million people (50% of NY State population)
- Delivers 1.1 billion gallons/day
- Operational Support Tool (OST) to optimize infrastructure, and avoid unnecessary (**$10B**+) water filtration costs
- HEFS forecasts are central to OST. The OST program has cost NYC under **$10M**

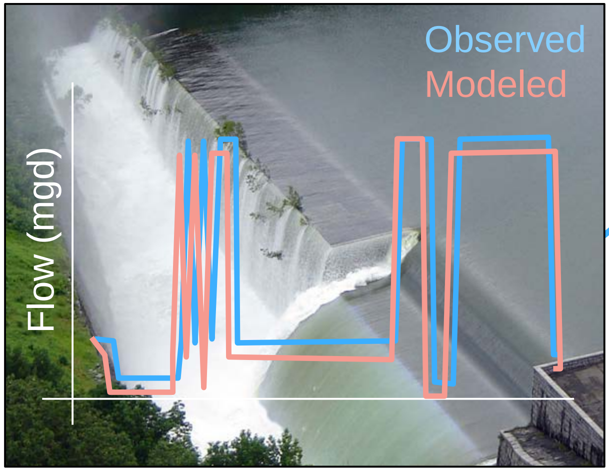
Early applications of HEFS



"Mission critical decision to manage shutdown of RBWT Tunnel based on HEFS forecasts"

"HEFS forecasts critical to protecting NYC drinking water quality during high turbidity events"

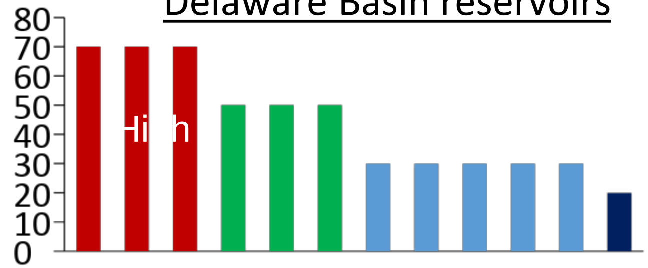
HEFS streamflow forecasts are used to optimize and validate the NYC OST for million/billion dollar applications



(Cannonsville Reservoir Spillway)

"HEFS forecasts help optimize rule curves for seasonal storage objectives in NYC reservoirs"

Risk to water availability from Delaware Basin reservoirs



"HEFS forecasts used to determine risks to conservation releases"

Early applications of HEFS

Forecast Informed Reservoir Operations (FIRO) in Russian River Watershed

- Multi-Agency study on Lake Mendocino
- Can we enhance reservoir operations and use of available storage by using forecasts to inform decisions about releasing or storing water?
- HEFS forecasts are central to optimized forecast-based reservoir operations
- Supports water control manual change request for Lake Mendocino
- Process can be replicated in other watersheds

HEFS Next Steps and Priorities

- Implement GEFSv12 forcings into operations
- Extend implementation of hydrologic post-processor (including regulated locations)
- Address performance in extreme events
- Allow for non-12Z HEFS operations
- Formalize Validation Testbed for enhancements
- Support “reforecast thinning” study with ESRL
- Expand probabilistic product suite leveraging emerging NWS and NWC Data Services

Other Challenges

- Effectively communicate uncertainty information in a form and context that is useful to our customers
  - Social Science research recommendations
  - Education and training
  - Context, validation and verification
  - Coherence with official single-value forecasts
  - Compatibility with decision support tools

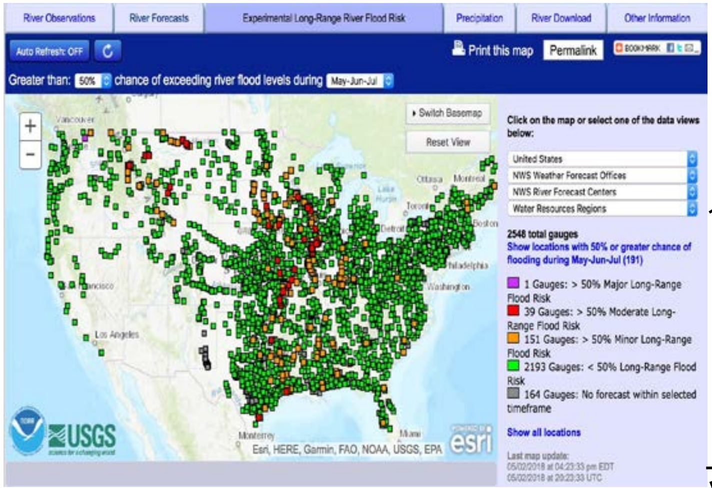
Other Challenges

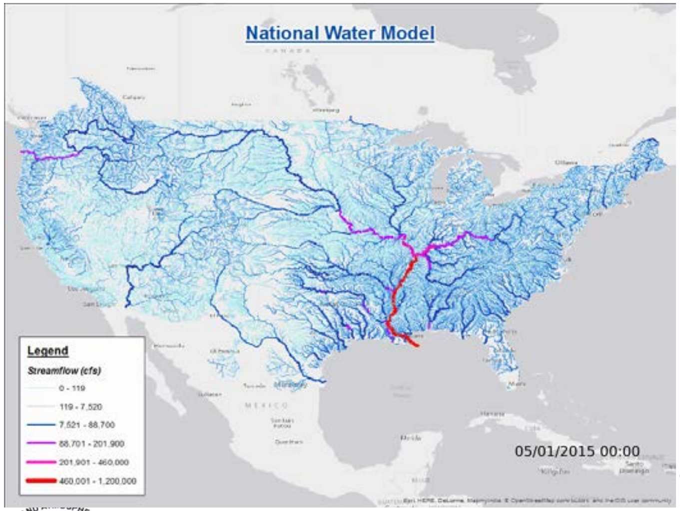
- Incorporating new forecasts for which hindcasts are not available to validate/train a decision post-processor (e.g., NBM)

- Realize the full utility of this probabilistic information for optimized decisions
  - Internal NWS (e.g. WFO warning operations)
  - External partners and customers

- Detailing the benefits to support investment
  - NCEP model reforecasts in HEFS dramatically expands the utility of output for decisions, **but** creates requirement for NOAA/NWS to continue to produce robust reforecasts

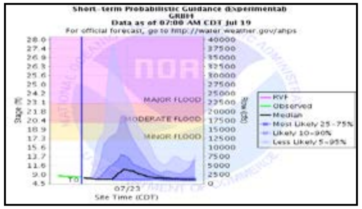
Water Resources Services - Existing and New





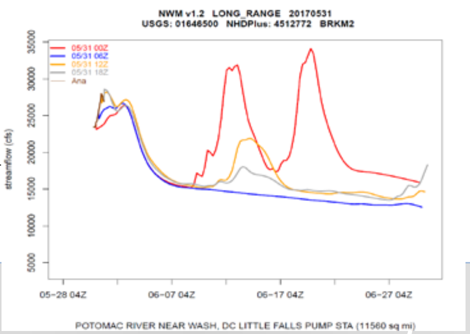
Current: Ensemble Streamflow Prediction (ESP)

- Historical climate forcings
- No accounting for hydrologic uncertainty or bias
- Suitable for long-range forecasting only
- limited number of graphical products



Near-term: Hydrologic Ensemble Forecasting Service (HEFS)

- Utilizes short, medium, and long range weather forecasts
- Captures total uncertainty and corrects for biases in forcings and streamflow
- Suitable for forecasting hours to years
- Wide array of data and user products



Future Services: NWM long-range ensemble prediction

- Potential to provide probabilistic forecasts at 2.7 million stream reaches

Questions

Ernie Wells
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Summary

- As HEFS is rolled out over the next few years, applications for decision support are expected to expand dramatically
  - Warning Operations and Emergency Services
  - Resource Management (water supply, flood control, fisheries, ecosystems, recreation, navigation)
- The future of NWS water intelligence resides in our ability to support optimized risk-based decisions
  - Ensemble-based (probabilistic) forecasting is foundational
    - Facilitates the realization of improved weather/climate forecasts
  - Utilizing NCEP model reforecasts in HEFS dramatically expands the utility of output for decisions, **but** creates requirement for NOAA/NWS to continue to produce robust reforecasts

Backup slides

Addressing meteorological uncertainty

Two elementary objectives of MEFP

1. Skillful “point” forecasts (at discrete times/basins)

- Capture inherent skill in the raw forcing inputs
- Add sufficient spread (based on past forecast errors)
- Correct for any systematic biases (based on past behavior)
- Downscale to hydrologic basins

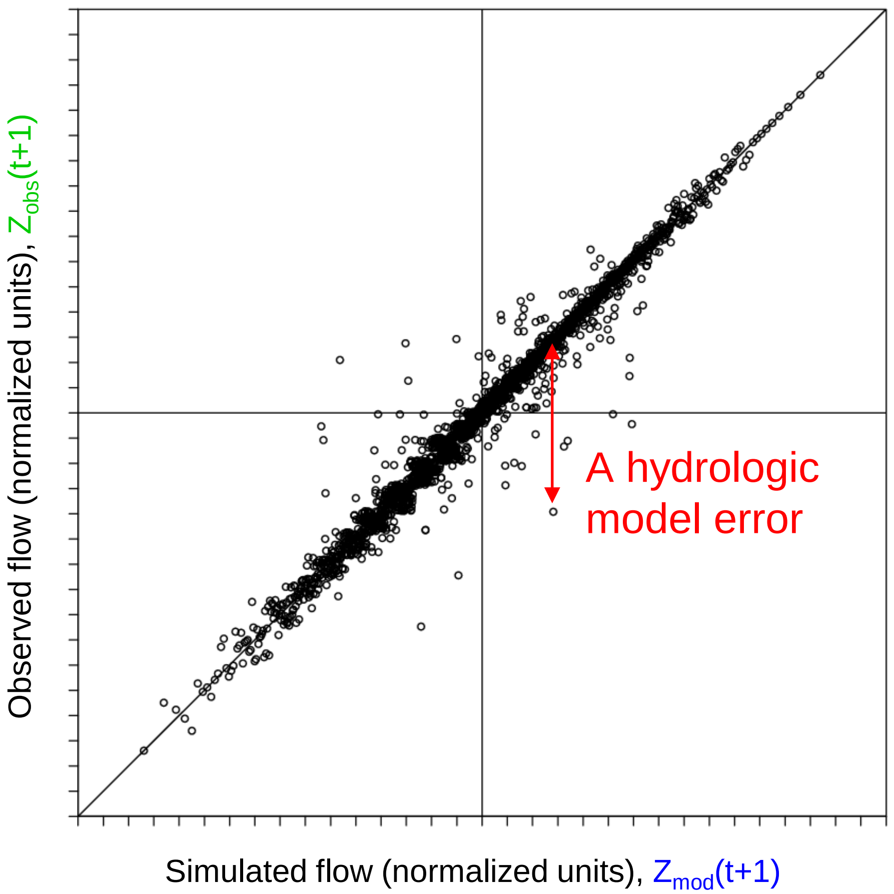
2. Point forecasts that are “stitched together” properly

- Patterns of precipitation and temperature must be consistent with observations in space and time, and with each other
- These patterns must be preserved across the different input sources (GEFS, CFSv2 etc.)

Addressing hydrologic uncertainty / biases

EnsPost ("flow processor")

- Does two things to flow forecast
  1. Adds spread to account for hydrologic model errors
  2. Corrects systematic biases
- Models relationship between observed flow and simulated flow (with observed forcing)
- Scatter around line of best fit represents the hydrologic error (i.e. no forcing uncertainty)
- Prior observation ("persistence") also included in model (not shown here)

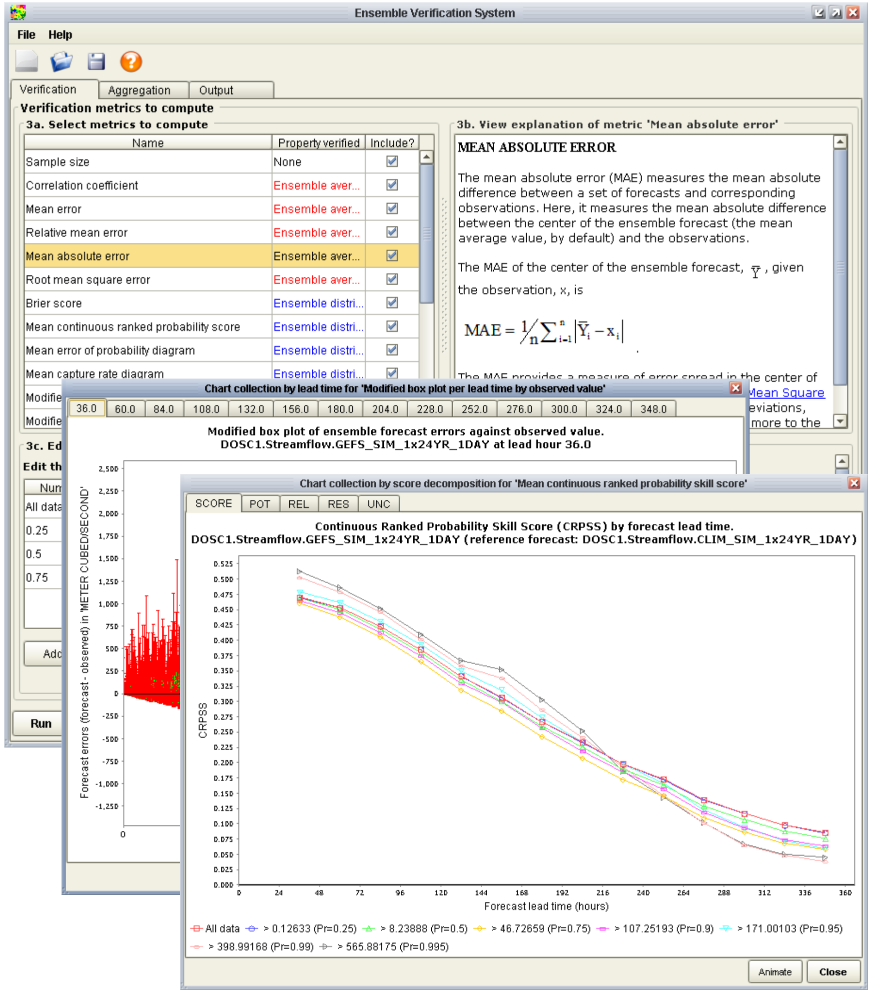


$$\hat{Z}_{obs}(t+1) = bZ_{mod}(t+1) + E(t+1)$$

Verification

Ensemble Verification System

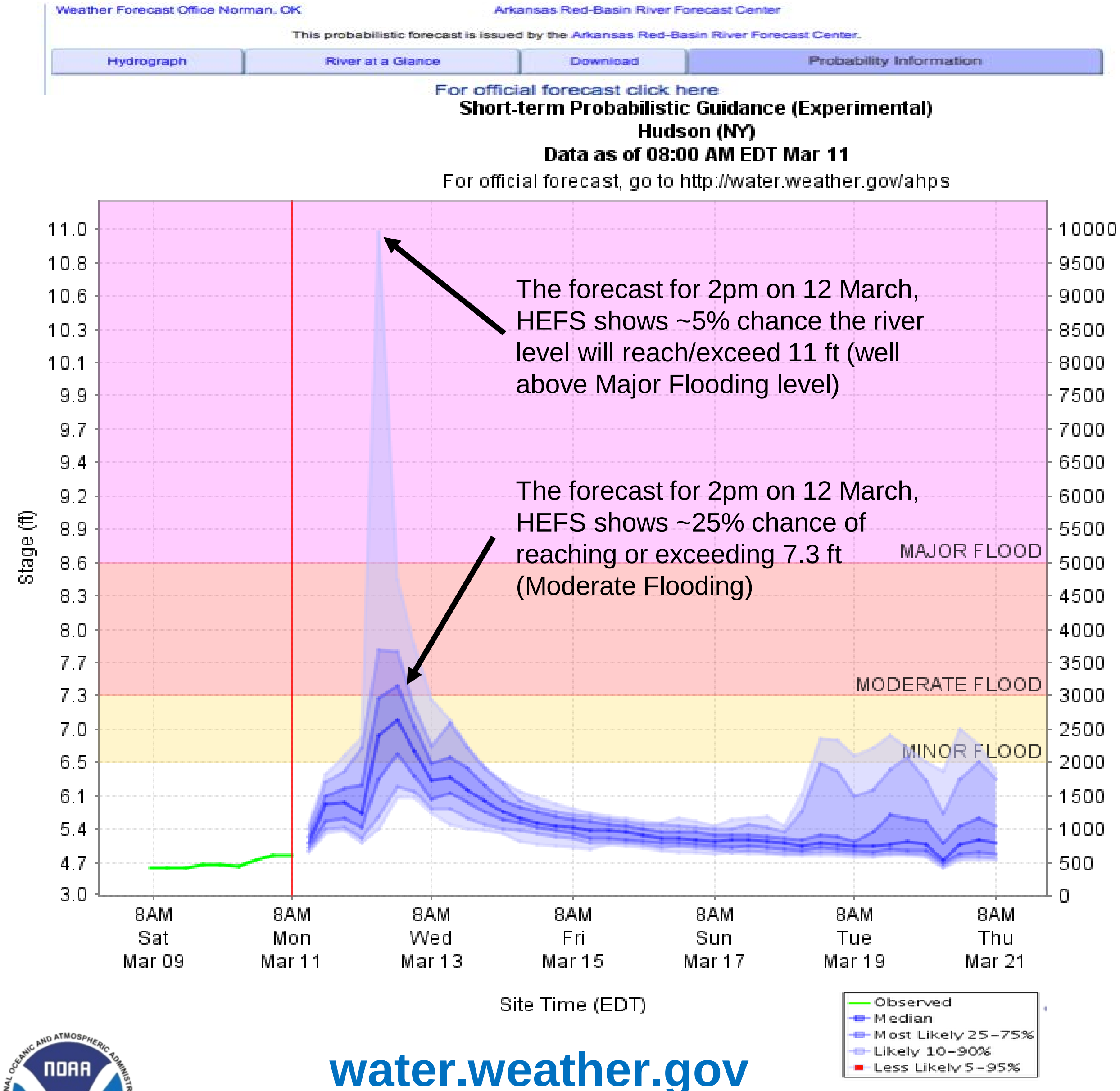
- Supports verification of HEFS including for precipitation, temperature and streamflow
- Verification of all forecasts or subsets based on prescribed conditions (e.g. seasons, thresholds, aggregations)
- Provides a wide range of verification metrics, including measures of bias and skill
- Requires a long archive of forecasts or hindcasts
- GUI or command-line operation



Other Challenges

- Effectively communicate uncertainty information in a form and context that is <u>useful to our customers</u>
  - Education and training
  - Context, validation and verification
  - Coherence with official single-value forecasts
  - Compatibility with decision support tools
- Realize the full utility of this probabilistic information for optimized decisions
  - Internal NWS (WFO warning operations)
  - External partners and customers (FIRO, EM response)
- Incorporating new forecasts for which hindcasts are not available to validate/train a post-processor
- Detailing the benefits to support investment
  - Internal NWS

Hydrologic Ensemble Forecast Service (HEFS)



- Initial HEFS products depict the uncertainty in short-range river forecasts
- 807 river locations display HEFS output in new experimental short-range product on AHPS
- 1165 river locations display HEFS output in long-range AHPS products
- 254 river locations display HEFS short-range output on CNRFC web pages
- HEFS ensemble forecasts provided directly to NYCDEP at 23 river locations supporting their water supply operations
- Baseline validation (30-year retrospective) of HEFSv1 output completed at 1528 river locations
- New river service locations will expand throughout 2019-20

water.weather.gov

Forecast quality: validation results

Focused validation of HEFS (2014/15)

- Temperature, precipitation and streamflow validated
- See: www.nws.noaa.gov/oh/hrl/general/indexdoc.htm

1. **Short- to medium-range forecasts** (1-16 days)
   - GEFS forcing used in the MEFP
   - Selected basins in four RFCs (AB, CB, CN, MA)
2. **Long-range forecasts** (1-330 days)
   - NYCDEP config. and basins (Delaware/Catskill)
   - GEFS (16 days) and CFSv2 (16-270 days)
   - Climatology after 270 days

Next steps

1. Complete initial implementation

- Encourage RFCs to release products more quickly
- Complete validation by 2020 (including routing across multiple RFCs)

2. Extend HEFSv1 implementation

- Addition of EnsPost
- Additional forcing (WPC/RFC, CFSv2, GEFSv12)

3. Implement GEFSv12 into operations

- Reforecasts available from NCEP by end of FY19 Q3

Next steps

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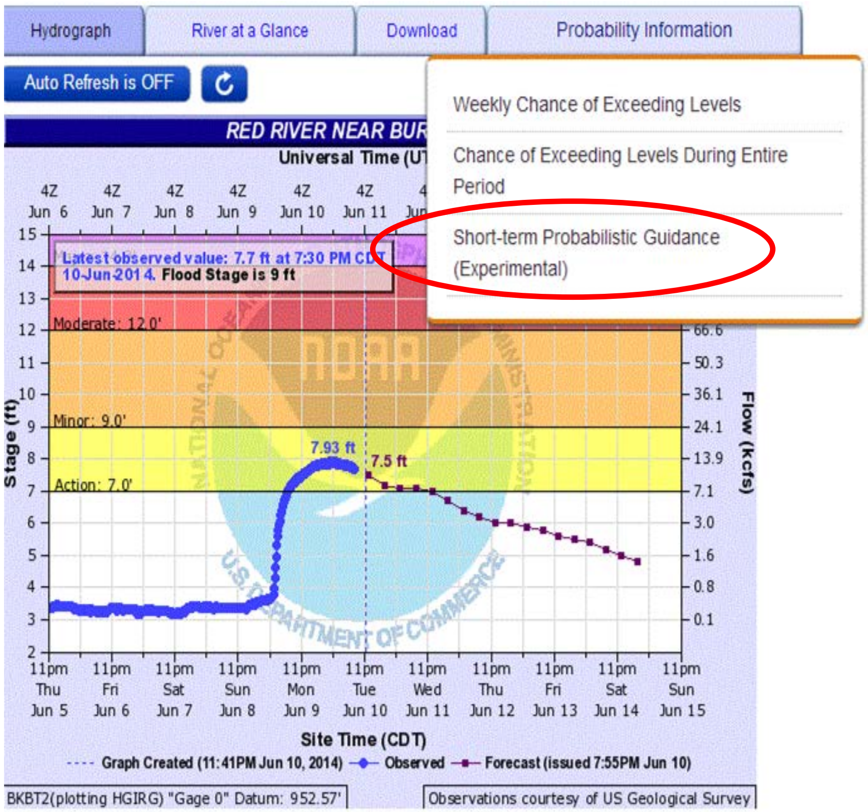
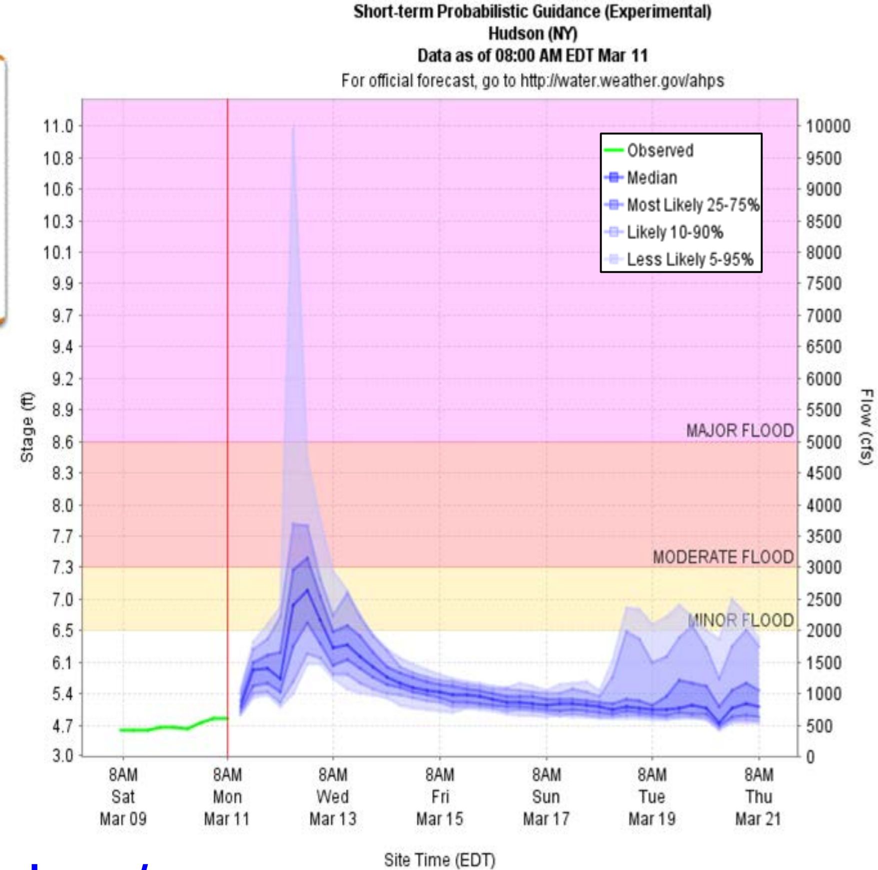
Example of national HEFS product

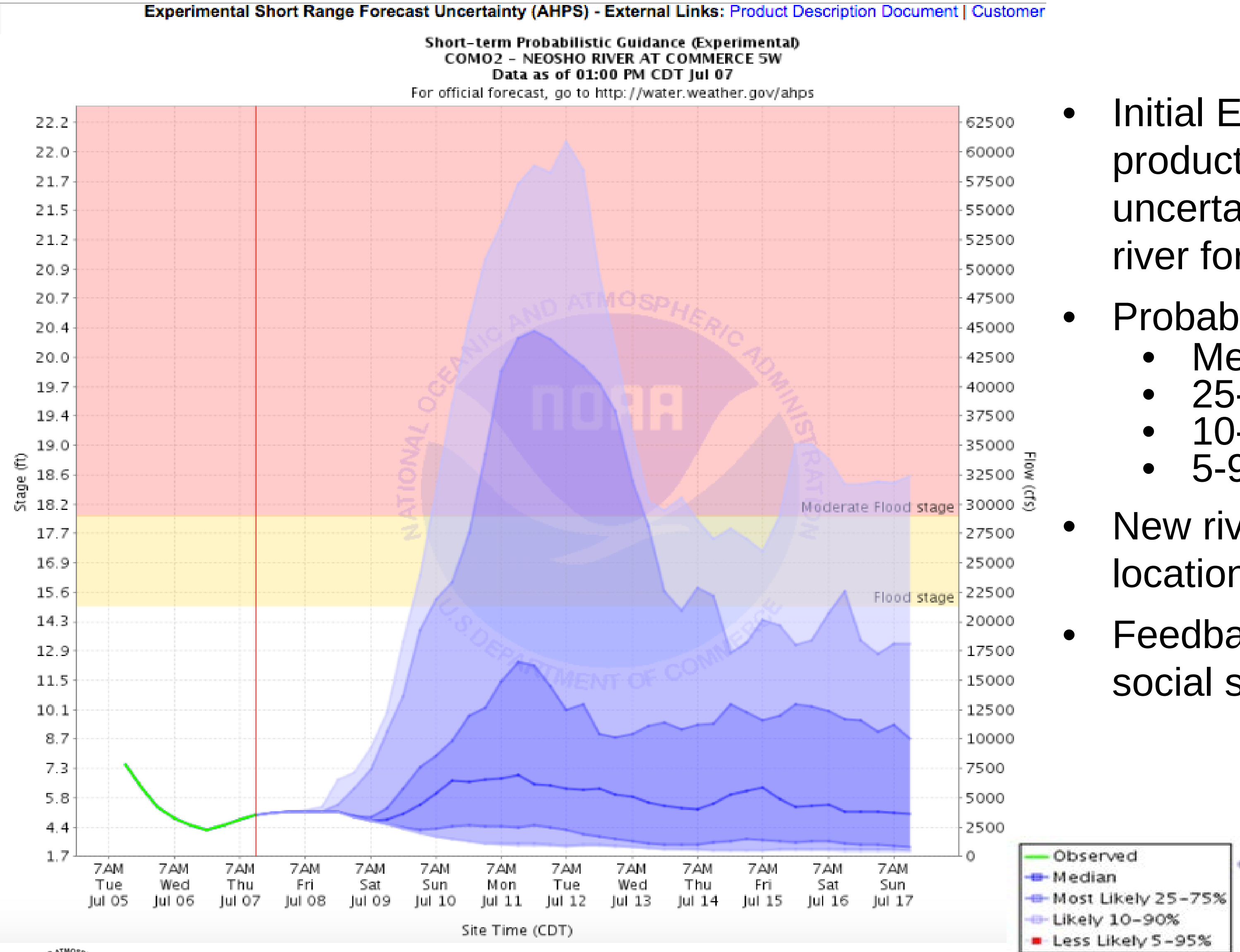
AHPS short-range probabilistic product





See: http://water.weather.gov/ahps/

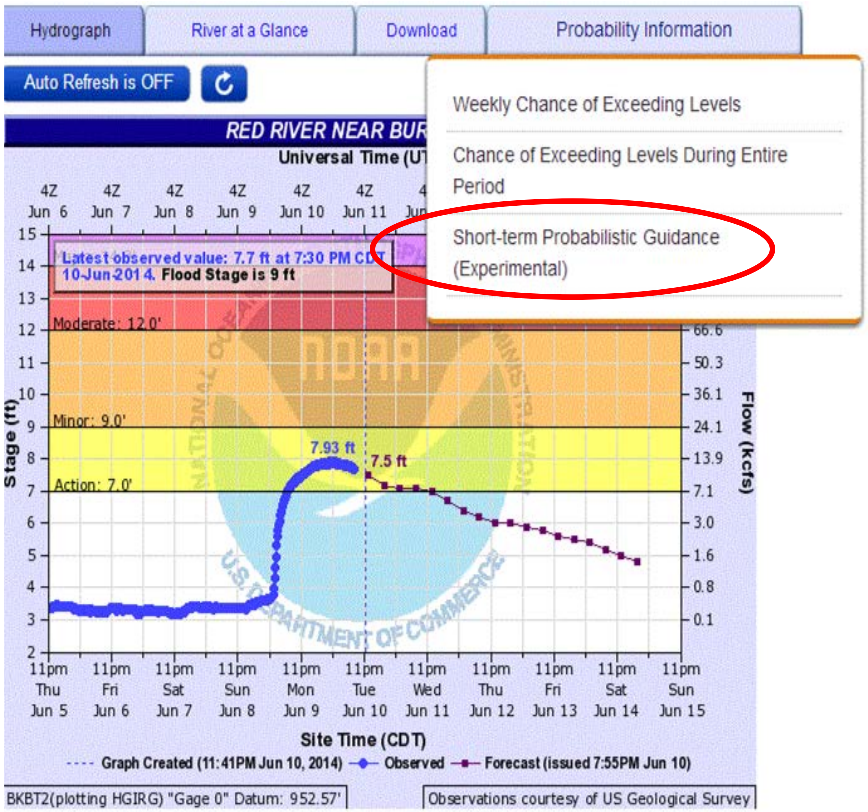
Example: short-range AHPS product

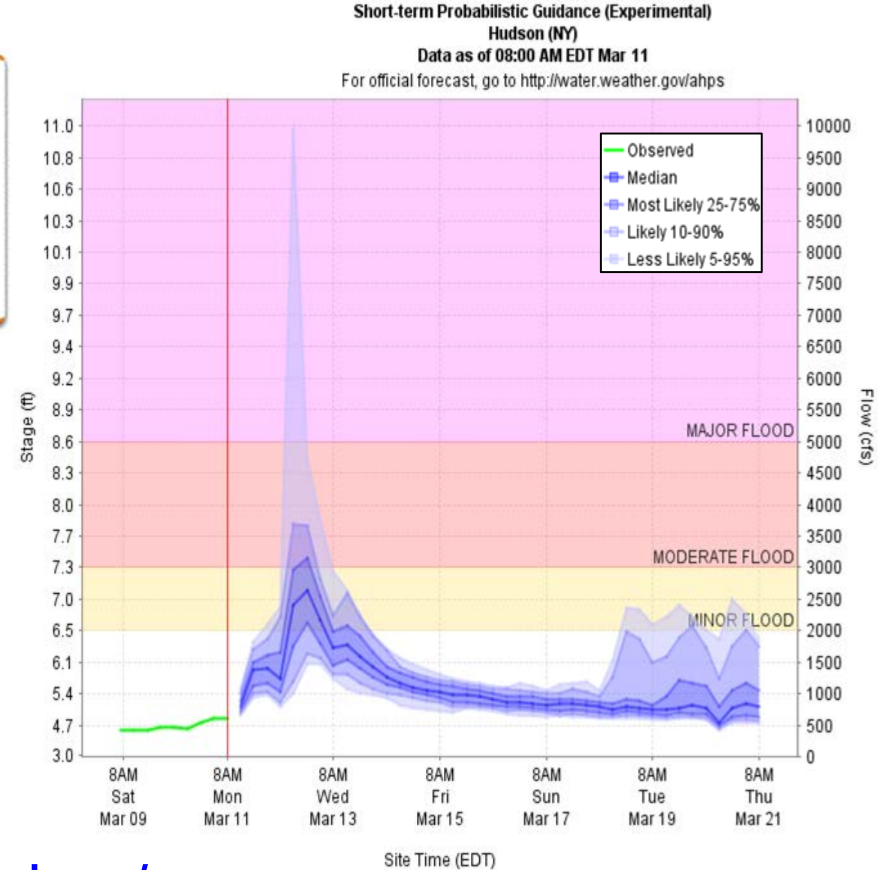


- Initial Experimental HEFS product depicts the uncertainty in short-range river forecasts
- Probability bands
  - Median (50%)
  - 25-75%
  - 10-90%
  - 5-95%
- New river service locations expanding
- Feedback via survey and social science studies

Example of national HEFS product

AHPS short-range probabilistic product





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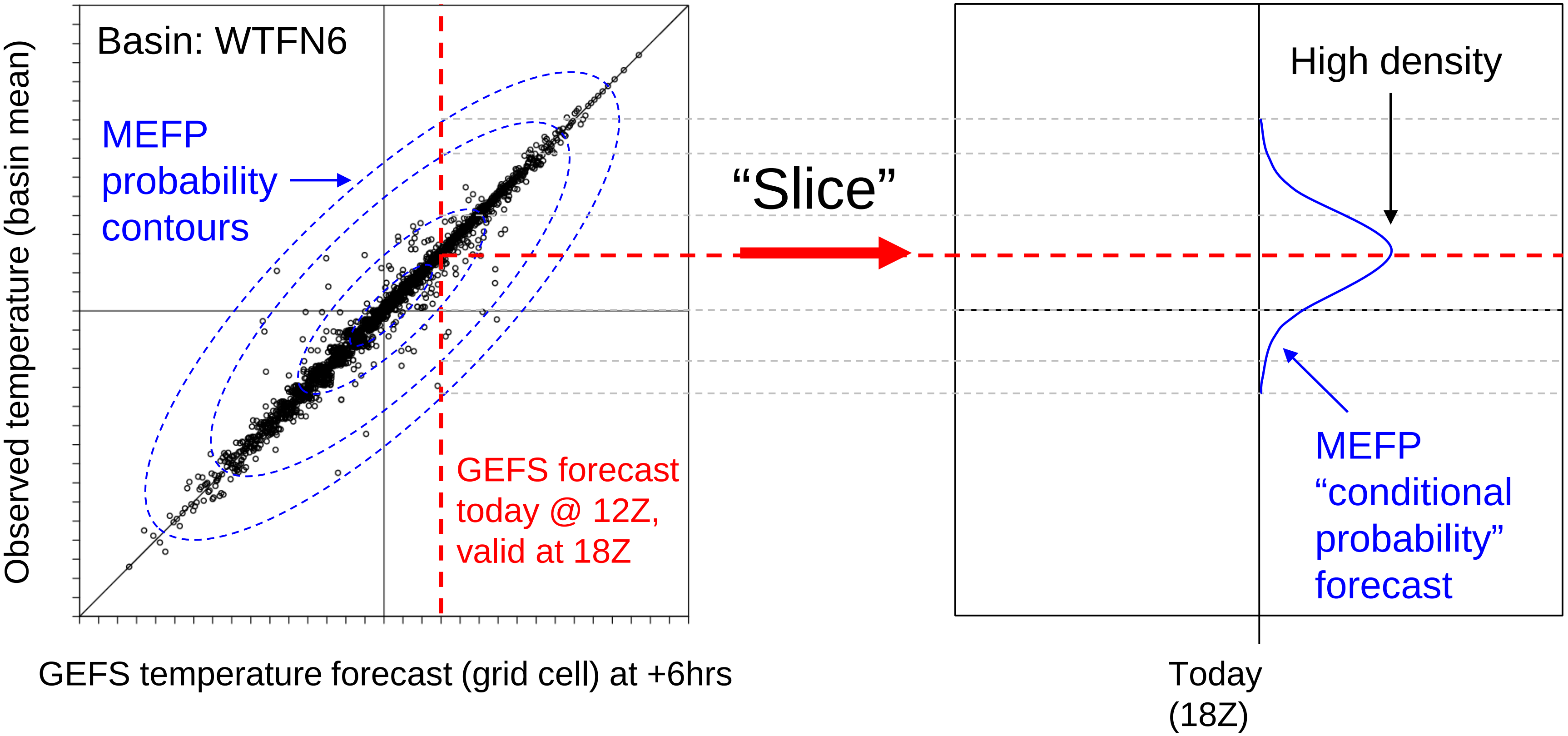
MEFP: point forecasts



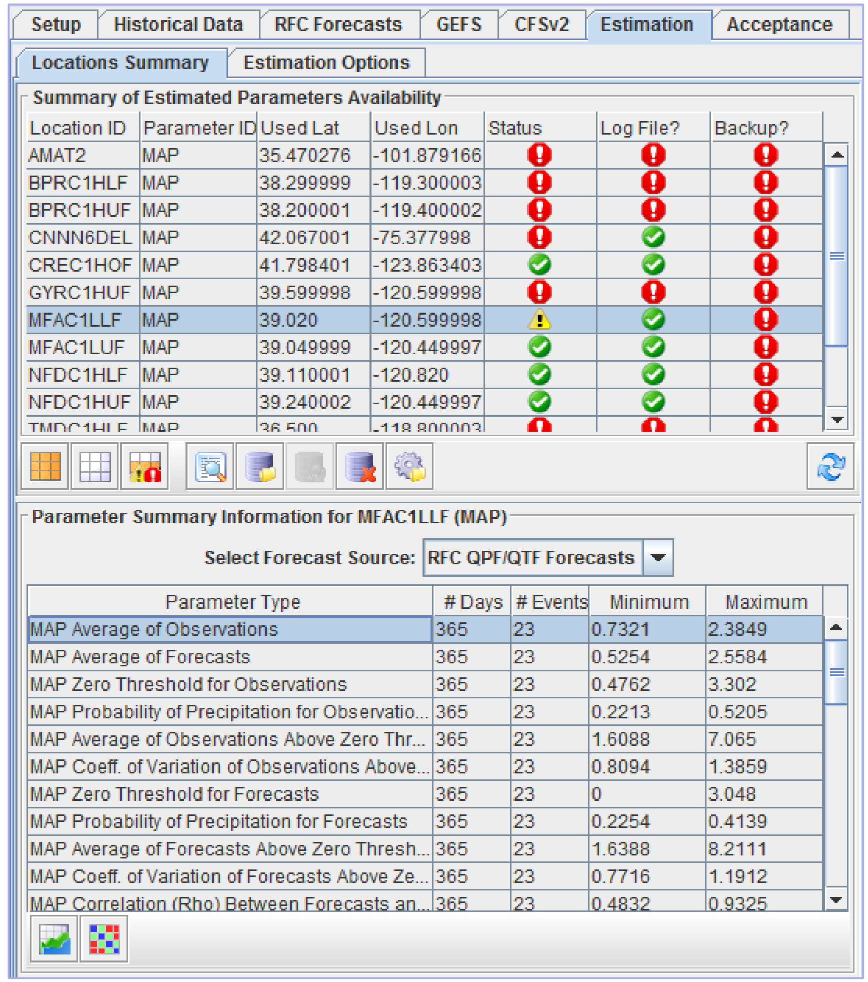
- MEFP models the historical “scatter” of raw forecast/observed pairs
- Best estimate of the future observation, given the raw forecast
- The raw forecast is used to “slice” the MEFP probability contours and provide a corresponding bias-corrected/downscaled forecast

What is the HEFS?

MEFP ("forcing processor")

- Does three things to raw forcing
    1. Adds sufficient spread to account for forecast errors
    2. Corrects systematic biases
    3. Downscales to basin
- The MEFP uses separate statistical models for temperature and precipitation
- The MEFP parameters are estimated using historical data (forecast archive or hindcasts)
- The outputs from the MEFP are FMAP and FMAT for a basin

MEFP Parameter Estimation Subpanel



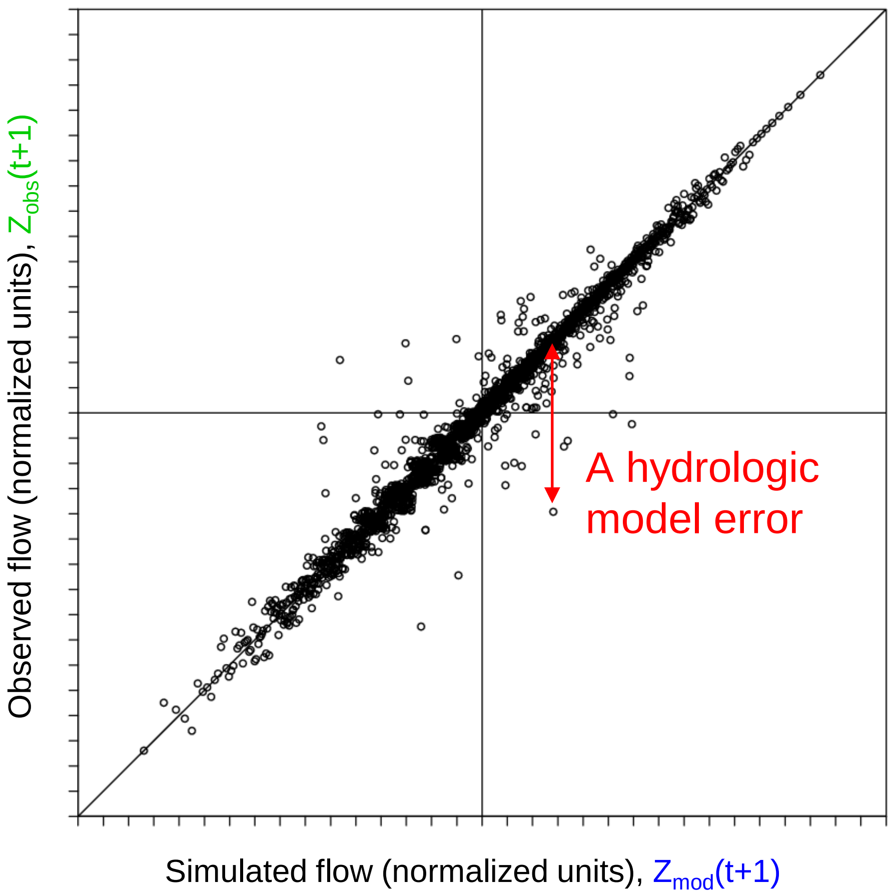
Location ID	Parameter ID	Used Lat	Used Lon	Status	Log File?	Backup?
AMAT2	MAP	35.470276	-101.879166			
BPRC1HLF	MAP	38.299999	-119.300003			
BPRC1HUF	MAP	38.200001	-119.400002			
CNNN6DEL	MAP	42.067001	-75.377998			
CREC1HOF	MAP	41.798401	-123.863403			
GYRC1HUF	MAP	39.599998	-120.599998			
MFAC1LLF	MAP	39.020	-120.599998			
MFAC1LUF	MAP	39.049999	-120.449997			
NFDC1HLF	MAP	39.110001	-120.820			
NFDC1HUF	MAP	39.240002	-120.449997			

Parameter Type	# Days	# Events	Minimum	Maximum
MAP Average of Observations	365	23	0.7321	2.3849
MAP Average of Forecasts	365	23	0.5254	2.5584
MAP Zero Threshold for Observations	365	23	0.4762	3.302
MAP Probability of Precipitation for Observatio...	365	23	0.2213	0.5205
MAP Average of Observations Above Zero Thr...	365	23	1.6088	7.065
MAP Coeff. of Variation of Observations Above...	365	23	0.8094	1.3859
MAP Zero Threshold for Forecasts	365	23	0	3.048
MAP Probability of Precipitation for Forecasts	365	23	0.2254	0.4139
MAP Average of Forecasts Above Zero Thresh...	365	23	1.6388	8.2111
MAP Coeff. of Variation of Forecasts Above Ze...	365	23	0.7716	1.1912
MAP Correlation (Rho) Between Forecasts an...	365	23	0.4832	0.9325

What is the HEFS?

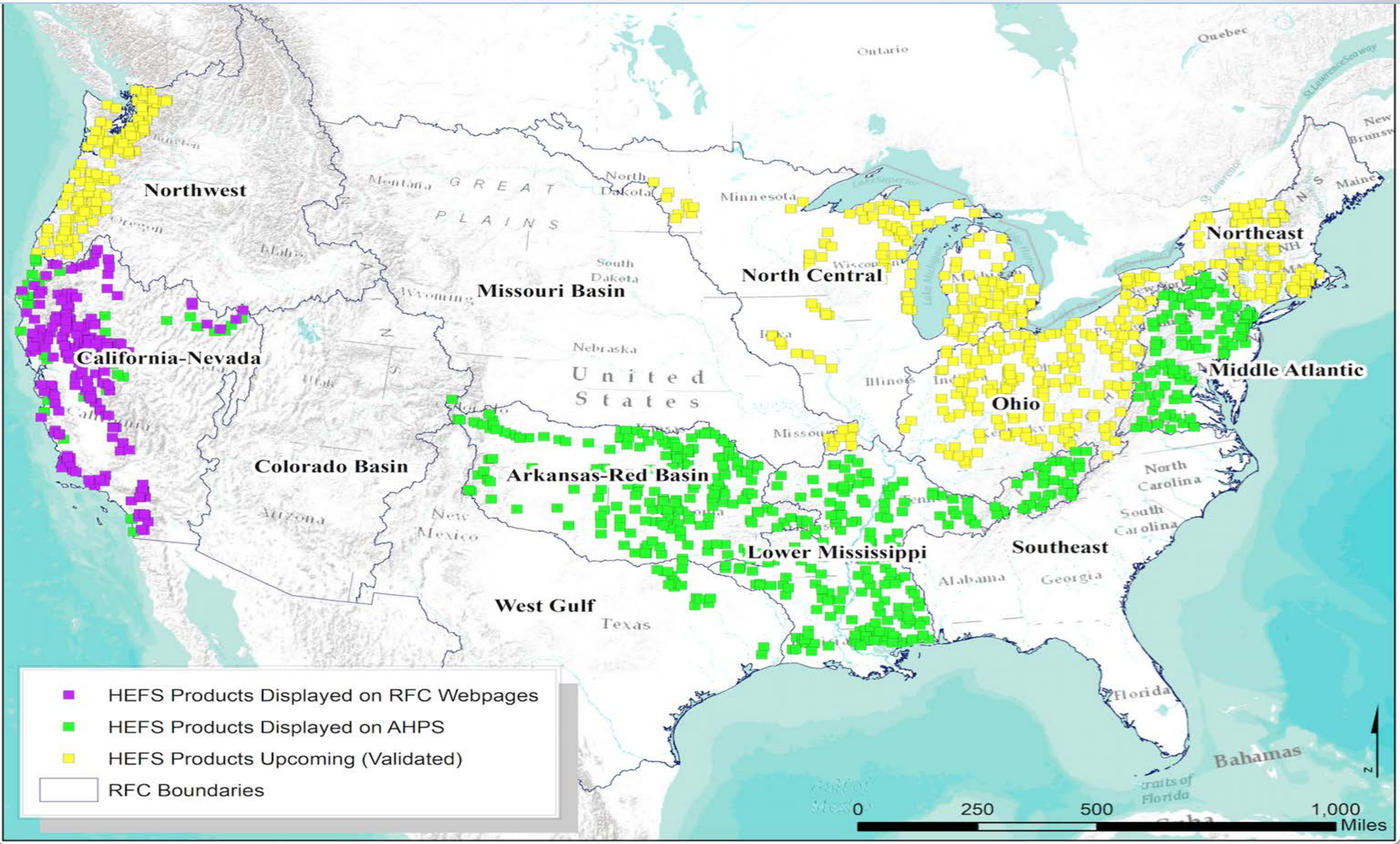
EnsPost ("flow processor")

- Does two things to flow forecast
  1. Adds spread to account for hydrologic model errors
  2. Corrects systematic biases
- Uses linear regression between observed flow and historical simulated flow (observed forcing)
- Scatter around line of best fit represents the hydrologic error (i.e. no forcing uncertainty)
- Prior observation ("persistence") also included in regression (not shown here)

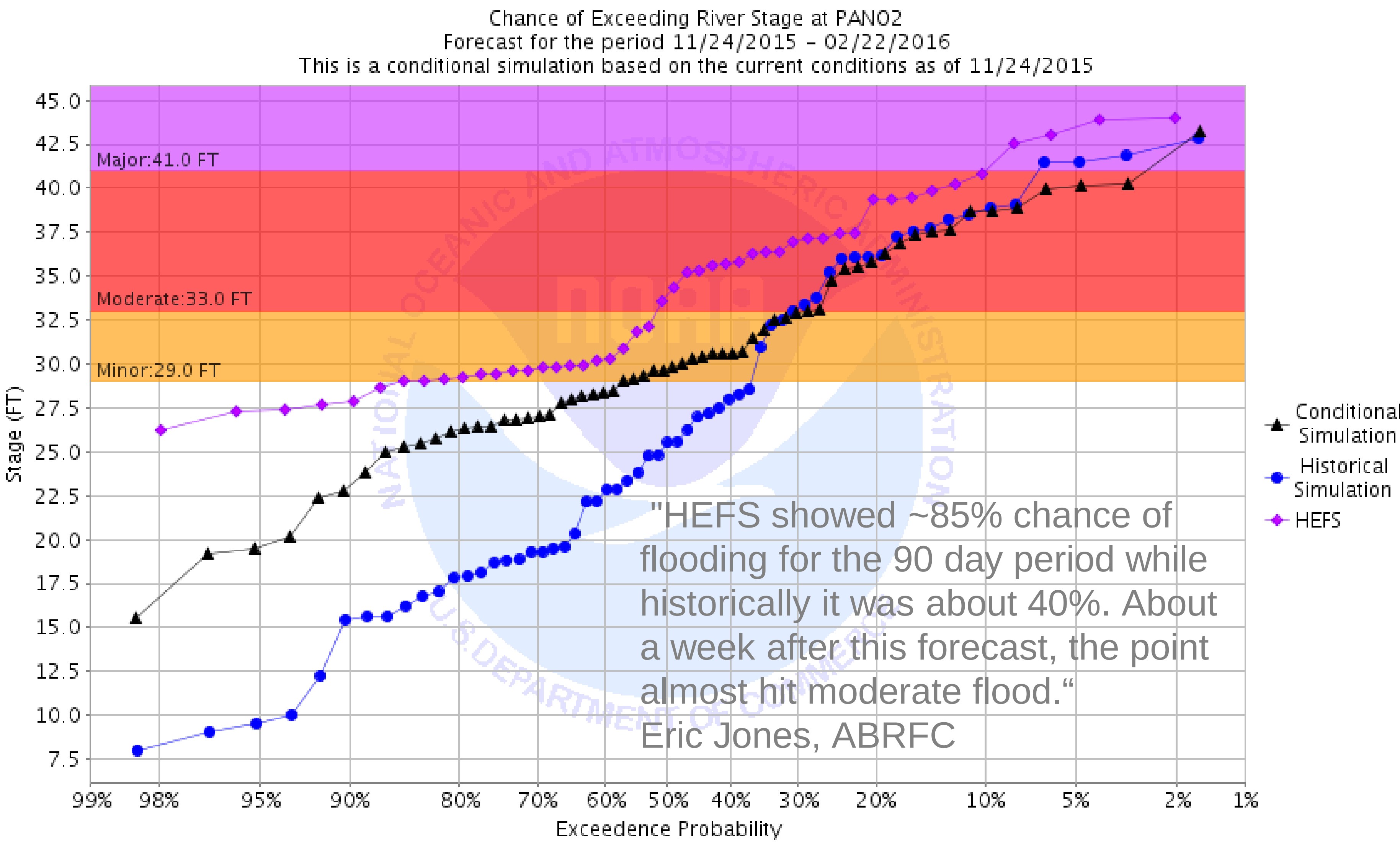


$$\hat{Z}_{obs}(t+1) = bZ_{mod}(t+1) + E(t+1)$$

HEFS Implementation Status



Example: Exceedance Probability Plot



"HEFS showed ~85% chance of flooding for the 90 day period while historically it was about 40%. About a week after this forecast, the point almost hit moderate flood.“
Eric Jones, ABRFC

Summary

Goal: improve NWS hydrologic services

Feature	ESP (old service)	HEFS (new service)
Forecast time horizon	Weeks to seasons	Hours to years, depending on the input forecasts
Input forecasts (“forcing”)	Historical climate data (i.e. weather observations) with some variations between RFCs	Short-, medium- and long-range weather forecasts
Uncertainty modeling	Climate-based. No accounting for hydrologic uncertainty or bias. Suitable for long-range forecasting only	Captures total uncertainty and corrects for biases in forcing and flow at all forecast lead times
Products	Limited number of graphical products (focused on long-range) and verification	A wide array of data and user-tailored products are planned, including standard verification

Methodology

How do we aggregate this information?

- Expert judgement
  - Combine knowledge of verification results and RFCs/basins (e.g. 20% skill means different things in different basins)
  - We have experience from earlier (focused) evaluations
  - We have documented this in initial guidance for RFCs
  - However, the Baseline Validation is also <u>educational</u>: we are learning what to expect as we see more results (and we are becoming much more efficient at producing them)
- We have provided the RFCs with an interactive tool with database to explore the verification statistics and classifications

HEFS Baseline Validation Status

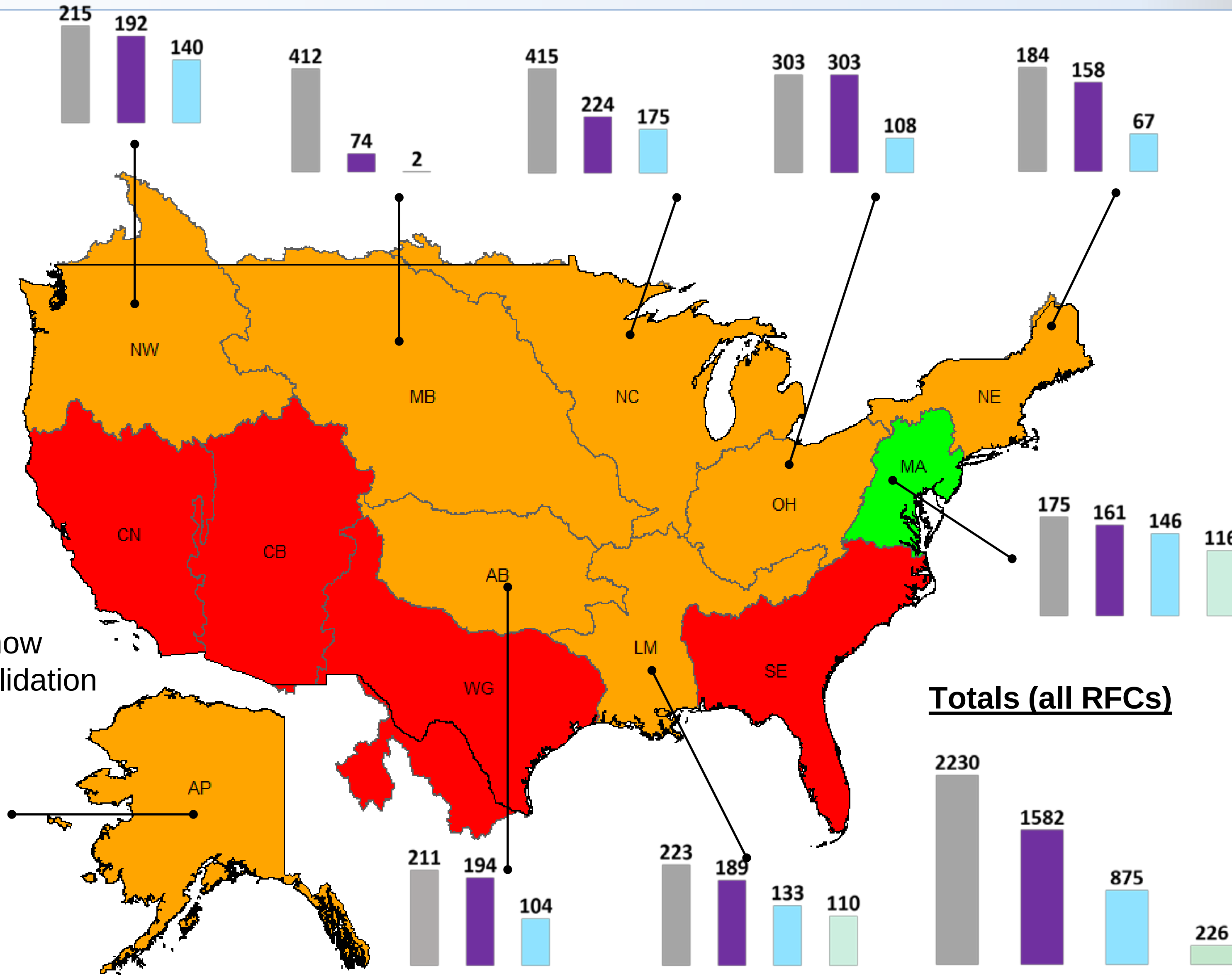
Map legend

- Finished
- Started
- Not started

Chart legend

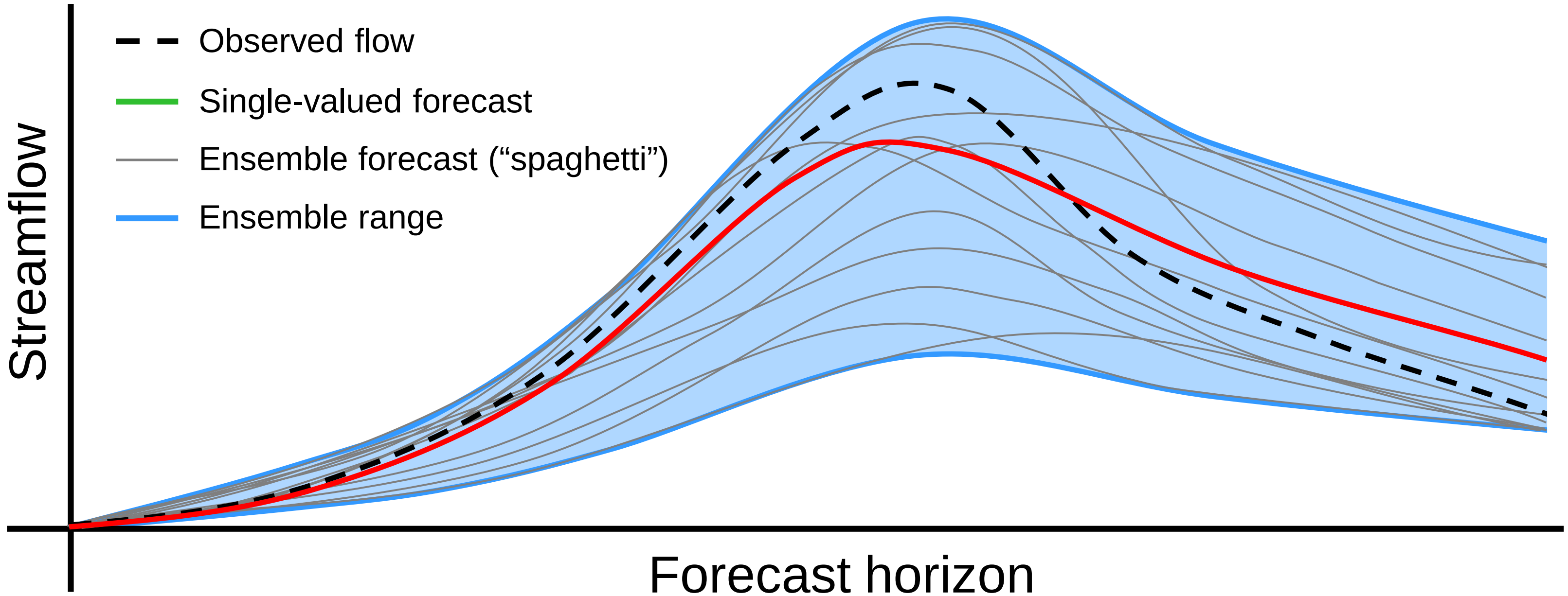
- Total sites
- Configured
- Validated
- On AHPS

Note: does not show other (non-BV) validation



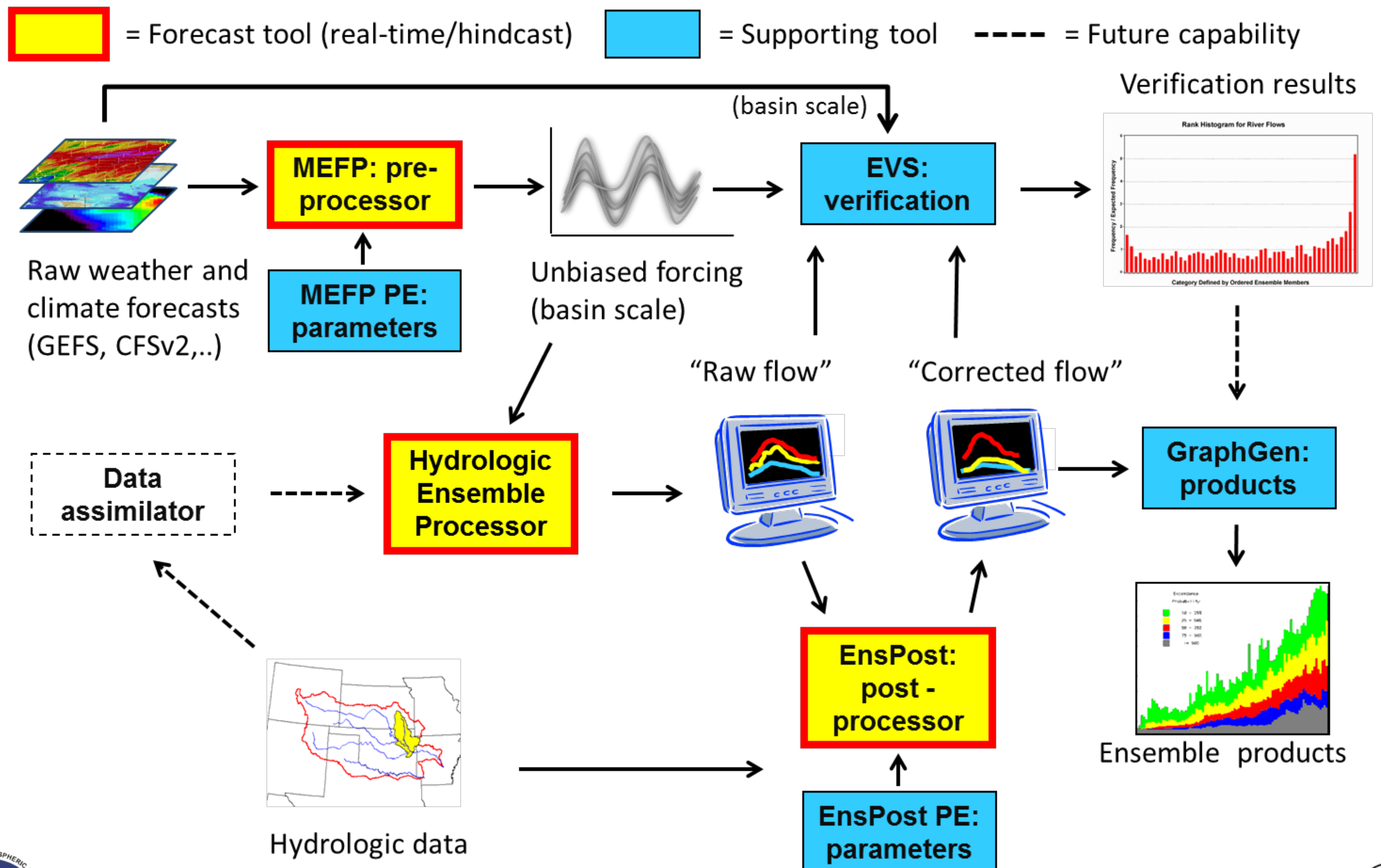
What are ensemble forecasts?

A collection of forecasts to capture uncertainty

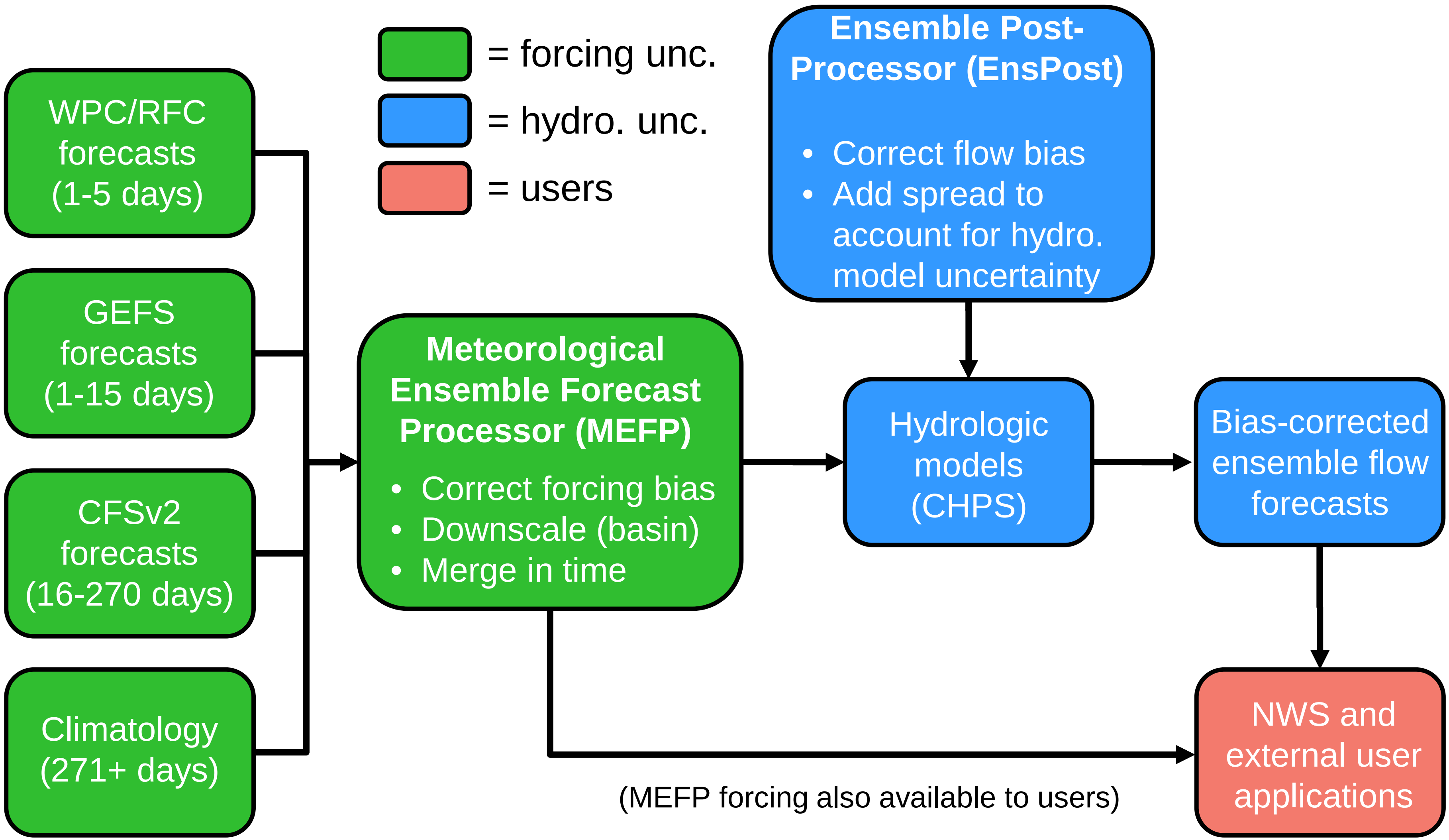


- Single-valued forecasts are known to be imperfect
- An ensemble provides a collection of forecasts
- Each ensemble member is one possible outcome

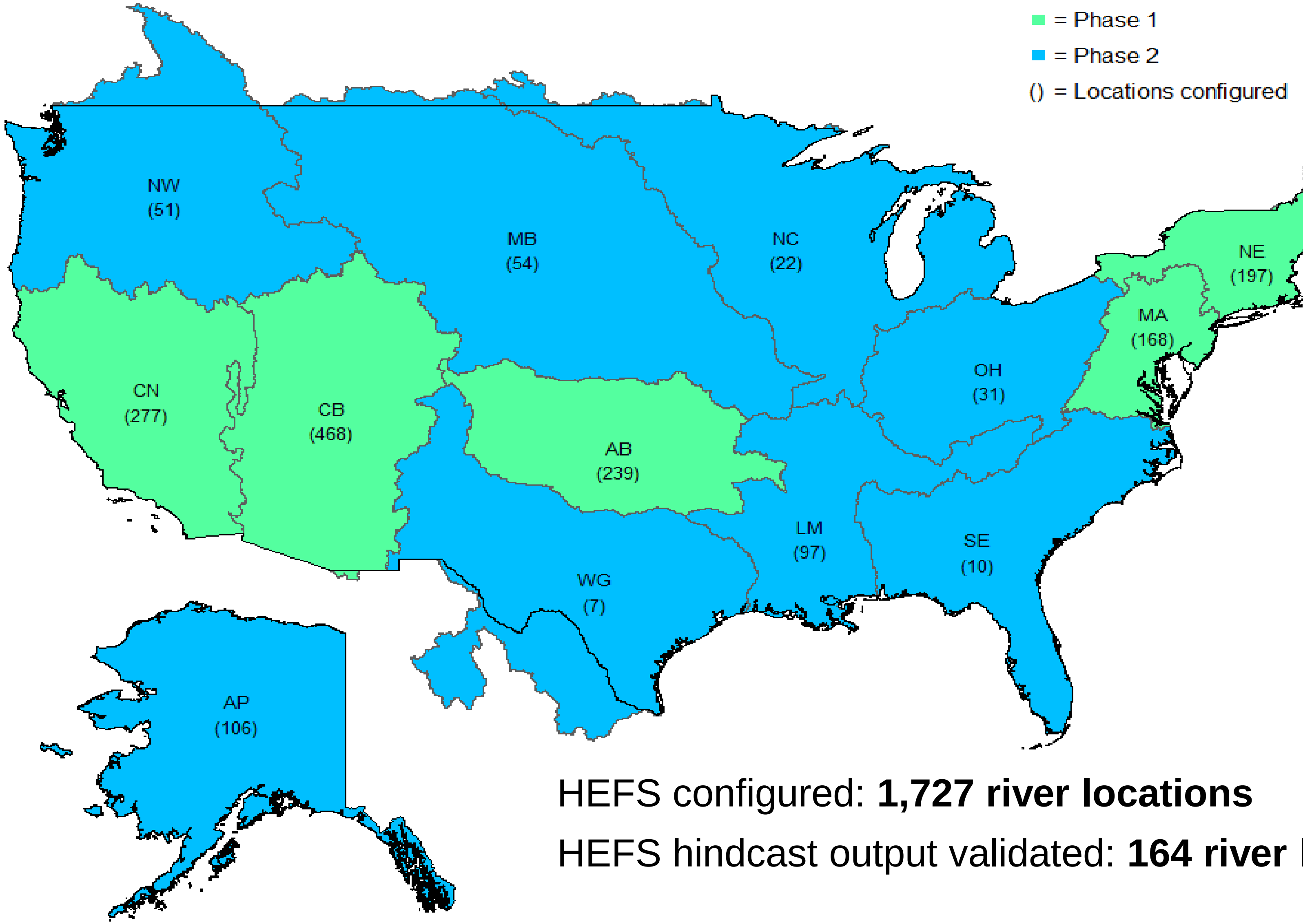
What is the HEFS?



What is the HEFS?



HEFS Implementation Status



HEFS configured: **1,727 river locations**

HEFS hindcast output validated: **164 river locations**

HEFS Publications / References

- Clark, M., Gangopadhyay, S., Hay, L., Rajogopalan, B., Wilby, R. 2004. The Schaake Shuffle: a method for reconstructing space-time variability in forecasted precipitation and temperature fields. Journal of Hydrometeorology 5 (1), 243-262.
- Herr, H.D. Krysztofowicz, R., 2005. Generic probability distribution of rainfall in space: the bivariate model. Journal of Hydrology 306, 234-263.
- Brown, J.D., Wu, L., He, M., Regonda, S., Lee, H., and Seo, D.J., 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 11/2014; 519:2869-2889. DOI: 10.1016/j.jhydrol.2014.05.028
- Brown, J.D. (2014) Verification of temperature, precipitation and streamflow forecasts from the Hydrologic Ensemble Forecast Service (HEFS) of the National Weather Service: an evaluation of the medium-range forecasts with forcing inputs from NCEP's Global Ensemble Forecast System (GEFS) and a comparison of 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. (2015) An evaluation of the minimum requirements for meteorological reforecasts from the Global Ensemble Forecast System (GEFS) of the National Weather Service (NWS) in support of the calibration and validation of the NWS Hydrologic Ensemble Forecast System (HEFS). Technical Report prepared by Hydrological Solutions Limited for the National Weather Service, Office of Hydrologic Development. 101pp.
- Demargne, J. , Limin Wu, Satish K. Regonda, James D. Brown, Haksu Lee, Minxue He, Dong-Jun Seo, Robert Hartman, Henry D. Herr, Mark Fresch, John Schaake, and Yuejian Zhu, 2014: The Science of NOAA's Operational Hydrologic Ensemble Forecast Service. Bull. Amer. Meteor. Soc., 95, 79–98.
- Kelly, K.S., Krzysztofowicz, R., 1997. A bivariate meta-Gaussian density for use in hydrology. Stochastic Hydrology and Hydraulics 11, 17-31.
- Schaake, J.C., Demargne, J., Hartman, R., Mullusky, M., Welles, E., Wu, L., Herr, H., Fan, X., Seo, D.J., 2007. Precipiation and temperature forecasts from single value forecasts, Hydrology and Earth System Sciences Discussions 4, 655-717.
- Wu, L., Seo, D.J., Demargne, J., Brown, J.D., Cong, S., Schaake, J.C., 2011: Generation of ensemble precipitation forecast from single valued quantitative precipitation forecasts for hydrologic ensemble prediction. Journal of Hydrology 399 (2011) 281-298

HEFS Training Workshops/Seminars

HEFS Validation Guidance, April 2015
- RFC Validation Guide
- Default_precipitation.evs
- Default_streamflow.evs
- Default_temperature.evs

HEFS Hindcasting Verification Workshop, Mar. 2015
- Workshop Agenda
- Seminar A - Introduction to the Workshop
- Seminar B - Hindcasting concepts and requirements
- Seminar C - Ensemble verification concepts and requirements
- Seminar D - Review results from Exercise 3
- Seminar E - Review results from Exercise 4
- Seminar F - Update on ensemble products and discussion
- Seminar G - HEFS project status and plans

HEFS Rollout Training Workshop, Aug. 2014
- Workshop Agenda
- Seminar A - Introduction to the Workshop
- Seminar B - HEFS Overview
- Seminar C - Basic Ensemble Theory Review [PDF]
- Seminar D - MEFP Theory
- Seminar E - EnsPost Theory
- Seminar F - HEFS ConOps
- Seminar G - Next Steps

HEFS Hindcasting and Verification Training Workshop, Feb. 2014
- Workshop Agenda
- Seminar A: Introduction to the Workshop
- Seminar B: Hindcasting concepts and requirements
- Seminar C: Review MEFP diagnostics
- Seminar C: Review MEFP diagnostics Answers
- Seminar D: Ensemble verification concepts and requirements
- Seminar E: Review results from Exercise 3
- Seminar F: Review results from Exercise 4
- Seminar G: Update on ensemble products and discussion
- Seminar H: CONOPS feedback and discussion
- Seminar I: HEFS project status and plans

HEFS 1.0.1 Training Workshop Seminars (only), Sep. 2013
- HEFS Workshop Agenda
- Seminar B - New for HEFSv1
- Seminar C - HEFS Science Validation Results
- Seminar D - ConOps Discussion
- Seminar E - Next Steps

HEFS User Guides / Software Manuals

HEFS

- EnsPost Configuration Guide
- EnsPost PE Configuration Guide
- EnsPost Users Manual
- EVS Manual
- HEFS Graphics Generator Products Installation Guide
- HEFS Overview and Getting Started
- Hindcast Robot Users Manual
- Hindcasting Guide
- MEFP Configuration Guide Data Ingest
- MEFP Configuration Guide Forecast
- MEFP Plug-in Framework Users Manual
- MEFP Users Manual
- MEFP WPC Plug-in Configuration Guide
- MEFPPE Configuration Guide

Training / Documentation Links

Comet Module

[Using the Hydrologic Ensemble Forecast Service (HEFS)]

HEFS Documentation and publications

http://www.nws.noaa.gov/oh/hrl/general/indexdoc.htm#hefs

VLAB - Hydrologic Ensemble Forecasting Service Community

https://vlab.ncep.noaa.gov/group/hydrologic-ensemble-forecasting

Next steps: HEFSv2

HEFSv2 priorities have been established

- The scope of the HEFSv1 was limited at the outset, in order to accelerate RTO and allow users to drive process
- Thus, we began RTO knowing some deficiencies
- Other issues discovered during RTO, and minor ones fixed
- Further issues may be identified by Baseline Validation, but these are likely to be basin-specific (config/calibration)
- RFCs and OWP have worked together to identify and rank both scientific and software priorities for HEFSv2:

  1. Improve MEFP forecasts of extreme precipitation
  2. Allow for non-12Z HEFS operations, including most recent forcing
  3. Improve guidance for use of HEFS/EnsPost in regulated rivers

Why use hydrologic ensemble forecasts?

Goal: better-informed water decisions