Hydrologic Ensemble Forecasting Service (HEFS) Communicating Uncertainty

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Presentation Outline

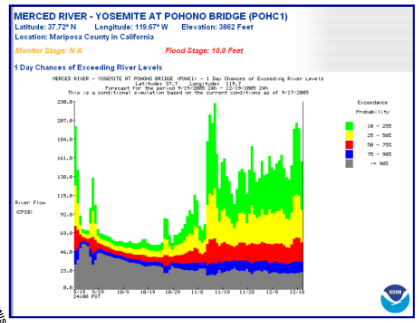
- HEFS design
- HEFS project implementation
- Challenges associated with effective communication

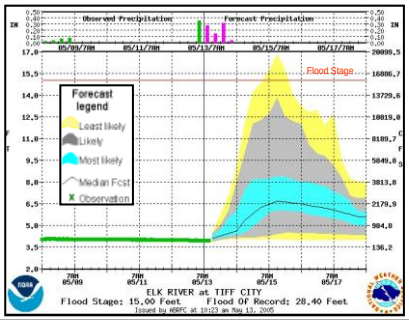
Push for HEFS Operational Implementation Begins in 2010/11

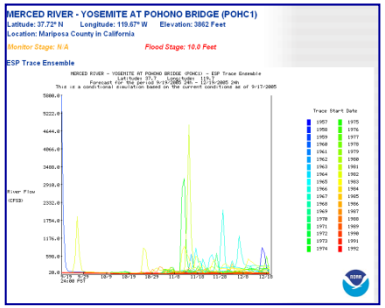
- *Well defined need for providing uncertainty estimates*
- *Limitations of current NWS ensemble forecasting*
- *HEFS science development maturing*
- *Prototype ensemble forecasting underway at RFCs*
- *CHPS implementation near completion*
- *Hydrology Program priority*
- *NYCDEP requirement for hydrologic ensembles*
  - *Assessment Team Established*

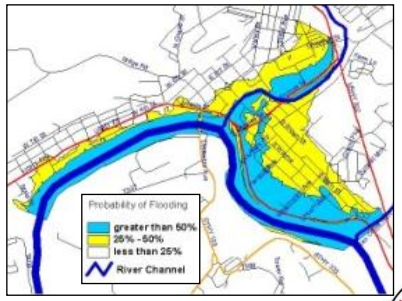
HEFS Service Level Objectives

- Produce ensemble streamflow forecasts:
  - Seamlessly span lead times from one hour to one year
  - Calibrated (unbiased, accurate spread)
  - Spatially and temporally consistent (linkable)
  - Effectively capture the information from current NWS weather to climate forecast systems
  - Consistent with retrospective forecasts
  - Verified
- Deliver a wide range of products









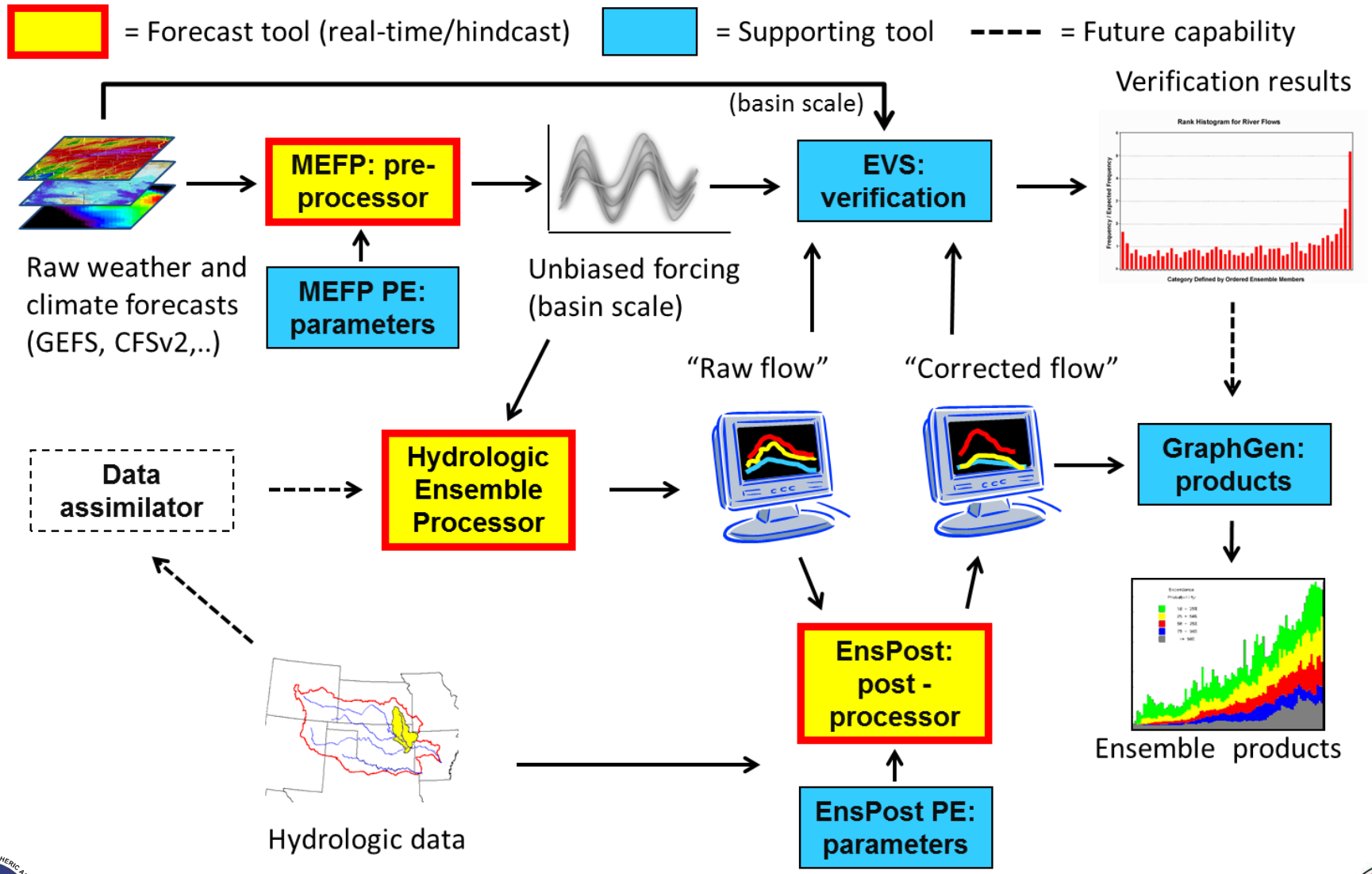
HEFSv1 Component Priority Matrix

Ensemble Forecast System Capability	Capability Priority	Prototype Component	Applied Science Readiness	Software Readiness	Ability to meet HEFS Objective	Component Version 1 Priority
Meteorological ensemble forecast processing	Required	**EPP3**	Medium	Medium	Medium	**Required**
		MMEFS	Low	High	Low	Medium
Hydrologic Processing	Required	**Hydrologic Processor**	High	High	High	**Required**
Automatic data assimilation	High	1D-VAR	Medium	High	Low	Medium
		2D-VAR	Medium	Medium	Low	Medium
		EnKF	Low	Medium	Medium	Low
Hydrologic ensemble forecast post-processing	High	**EnsPost**	Medium	High	Medium	**High**
		HMOS	Medium	High	Low	Low
		MSCM	Low	Low	Low	Low
		TBD(Augmented Gaussian regression) [1]	--	--	--	Medium
Ensemble forecast verification	Required	**EVS**	High	High	High	**Required**
Product generation	Required	**GraphGen**	High	High	High	**Required**
Product Dissemination / Data Services	Required	**Ad-hoc, existing (AHPS web, RFC web, AWIPS WAN, etc)**	Medium	Medium	Medium	**Required**
		Integrated Data Services	--	--	--	--

Key Findings / Recommendations

1. XEFS components forms reasonable basis for HEFSv1, but limited testing to date (basins and conditions) poses risk
2. Implement 5 Required and 1 High priority components for HEFS v1
3. MEFP will require most software/systems engineering effort
4. Significant capability gaps in ensemble post-processing and data assimilation. Recommend focused science development toward improved post-processing in parallel w/v1 development.
6. CHPS provides ready framework but some unknowns
7. Establish RFC test team to test/implement HEFS software builds
8. RFC Training is critical and will require significant resources
9. Outreach needed for internal and external users of ensemble output
10. HEFSv1 “will not completely satisfy all service-level objectives”

HEFS Components



Major Accomplishments (2011-2014)

- Delivered 3 software development/test builds of HEFSv1
  - MEFP recode and enhancement with GEFS and CFSv2
  - Added diagnostics and improved maintainability, usability
  - EnsPost recode and enhancements
- Implemented and tested HEFS builds at 5 RFCs
- Delivered 4 training workshops to test RFCs and support team
- Completed 3 initial phases of HEFS evaluation
- Met NYCDEP commitments on schedule (31 Dec 2013)
- Completed Initial Concept of Operations for HEFS
- On schedule to complete software rollout to remaining 8 RFCs

Phased science validation

Three phases completed & documented

Phase I: medium-range (1-14 days), frozen GFS (discont.)

- Selected basins in four RFCs (AB, CB, CN, MA)

Phase II: long-range (1-330 days), GEFS+CFSv2+CLIM

- Selected basins in MA and NE (in support of NYCDEP)

Phase III: medium-range, latest GEFS

- Same design as Phase I to establish gain from GEFS

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

Two papers forthcoming in JoH special issue (Brown et al.)

Evaluation - *Strengths*

- Provides a common framework for ensemble forecasting
- The HEFS broadly performs as anticipated
  - Captures skill in inputs (weather and climate forecasts)
  - Produces unbiased outputs (accurate mean, reliable spread)
  - Quantifies the total uncertainty, including hydrologic uncertainty
  - Integrates met inputs spanning short to long lead times
  - Produces spatially and temporally consistent forecast ensembles
  - But, only considered small set of locations and scenarios
- For medium-range forecasting, the **GEFS adds meaningful extra lead time** for all forecast variables compared to the frozen GFS
  - 1-2 days for streamflow and precipitation and 2-4 days for temperature

Evaluation - *Weaknesses*

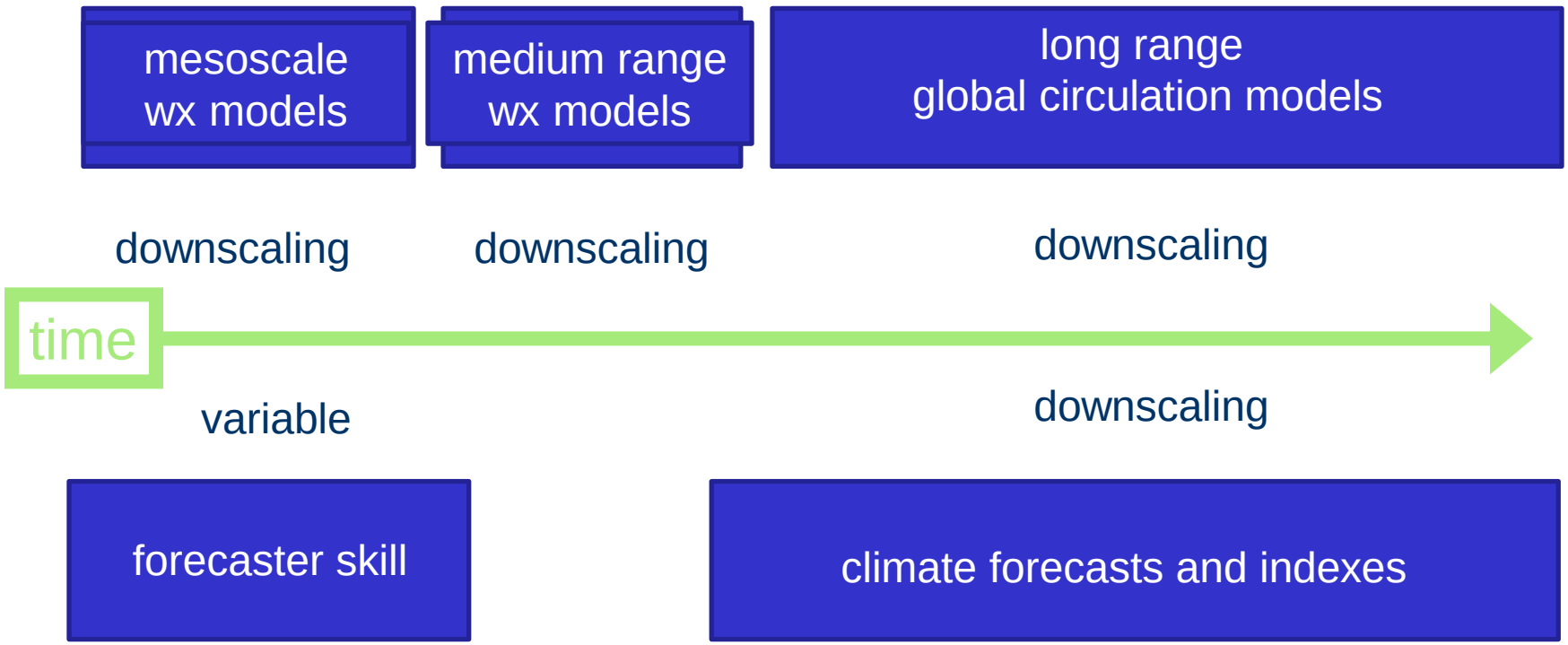
- For long-range forecasting, HEFS value is more modest
  - The CFSv2 generally adds little or no skill when compared to climatology
  - But MEFP should be able to capture skill with improved climate information
- Current Ensemble Post-Processor is limited
  - Lumps all hydrologic uncertainties and biases, which reduces ability to model the total uncertainty effectively
  - Primarily benefits short-range ensembles (lead time 1-5 days)
  - Issues with temporal consistency (discontinuities): needs science solution
  - Automated data assimilation needed as a long-term investment (reduces lumping together of uncertainties, hence reduces pressure on EnsPost)
  - Not designed for correcting regulated flows. Should leverage HRC work on this
- Some issues with the MEFP forcings
  - "Canonical events", which try to capture skill at different temporal scales. Causing problems with lack of smoothness/discontinuities in P and T.
  - Biases in Probability of Precipitation (PoP). Currently under investigation.

Current Implementation Status

- ABRFC - MEFP at 440 basins for precipitation and 103 basins for temperature, ensemble streamflow at 239 points, and EnsPost and Graphics Generator for ~140 of those points.
- CBRFC – MEFP at 622 sub-basins, ensemble streamflow for 331 locations, and EnsPost at 234 locations
- CNRFC - MEFP at 319 basins for precipitation and temperature, ensemble streamflow at 199 points, and EnsPost for 30 points
- MARFC – MEFP, ensemble streamflow, and EnsPost, and Graphics Generator at 53 basins including 14 locations supporting NYCDEP
- NERFC HEFS coverage includes the MEFP (precipitation and temperature) and ensemble streamflow at 31 locations and EnsPost at 17 locations.

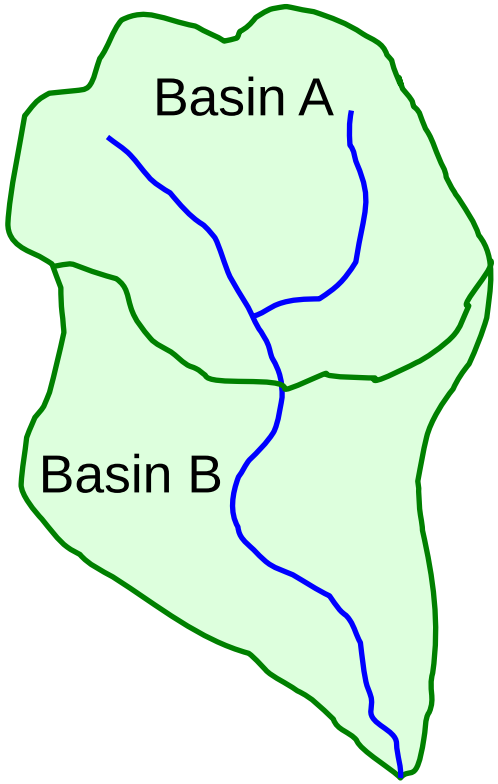
Ensemble Forecasting Challenge

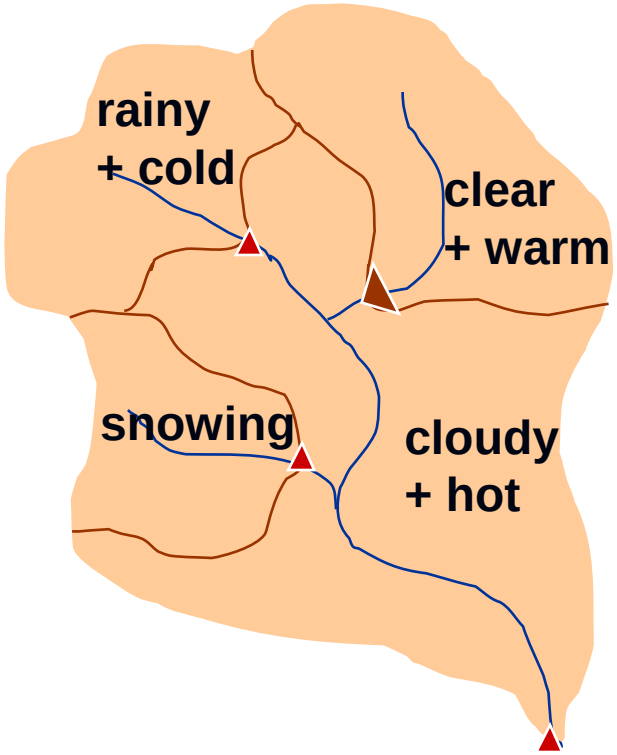
- **Mesh ensemble forcings from short, medium, and long range techniques.**



Ensemble Forecasting Challenge

- Ensure forecast ensembles maintain spatial and temporal relationships across many scales

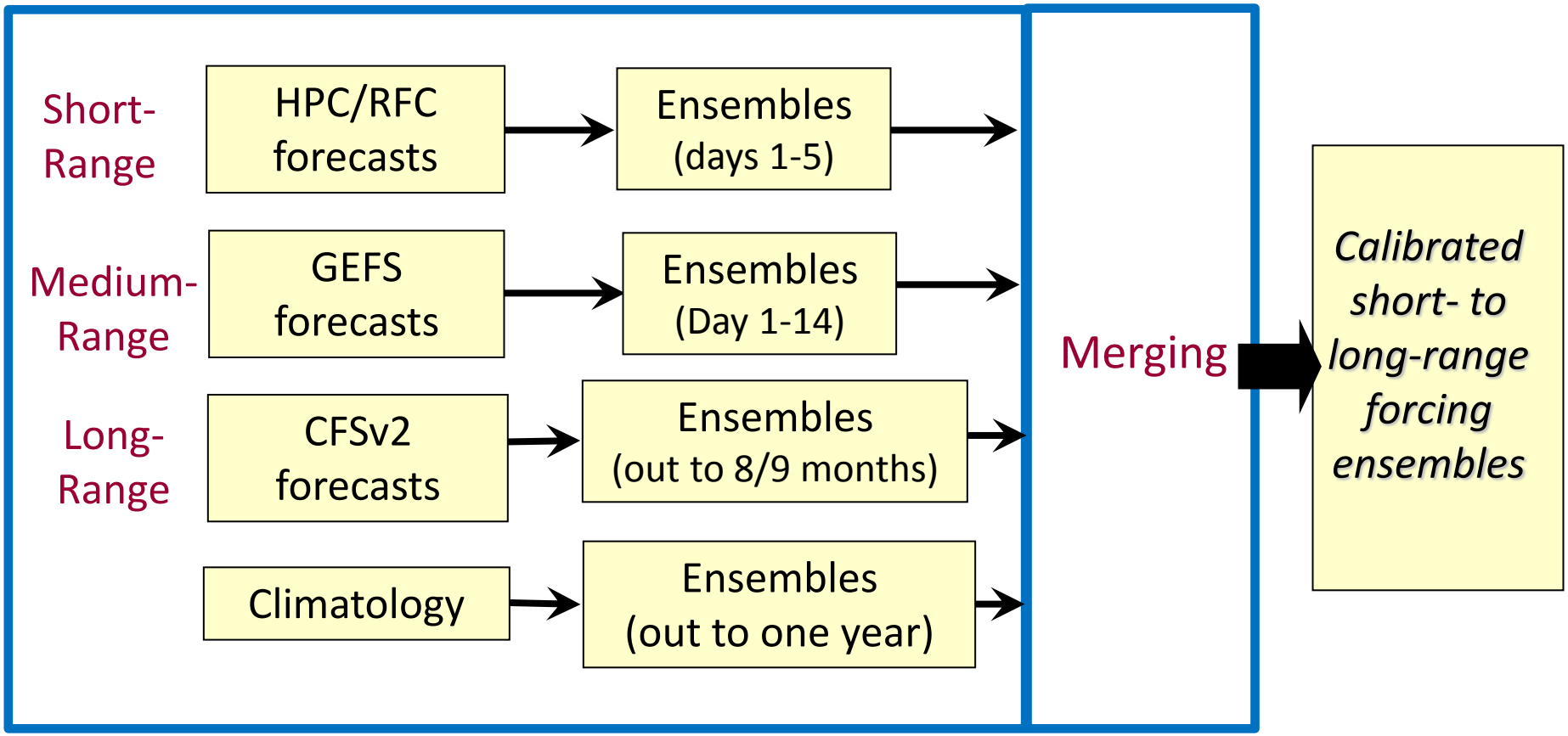




Irrational outcomes

- Similarly, ensure consistency between precipitation and temperature is preserved in the forecast ensembles.

Meteorological Ensemble Forecast Processor



MEFP Methodology

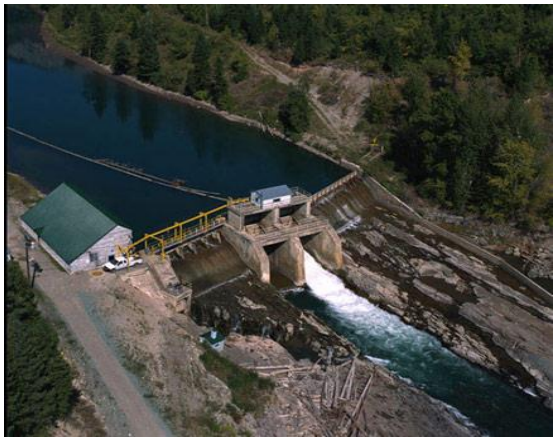
Goal: Produce reliable ensemble forcings that capture the skill and quantify the uncertainty in the source forecasts.

Key Idea: Condition the joint distribution of single-valued forecasts and the corresponding observations using the forecast.

- Use forecasts from multiple models to cover short- to long-range.
- Model the joint probability distribution between the single-valued forecast and the corresponding observation from historical records.
- Sample the conditional probability distribution of the joint distribution given the single-valued forecast.
- Rank ensembles based on the magnitude of the correlation coefficients between forecast and observation for the time scales and associated forecast sources.
- Generate blended ensembles (using Schaake Shuffle) iteratively for all time scales from low correlation to high correlation.

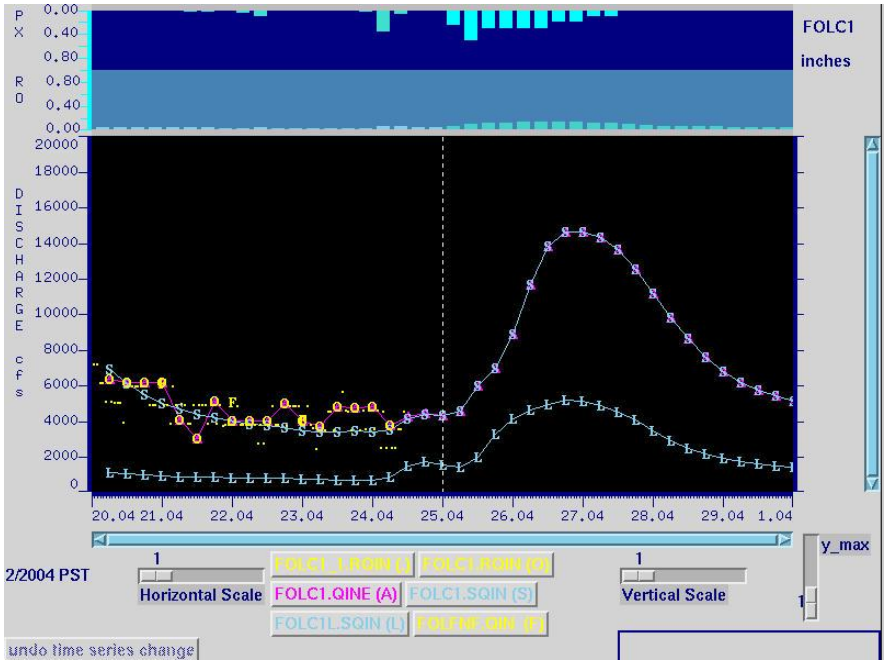
Ensemble Forecast Challenge

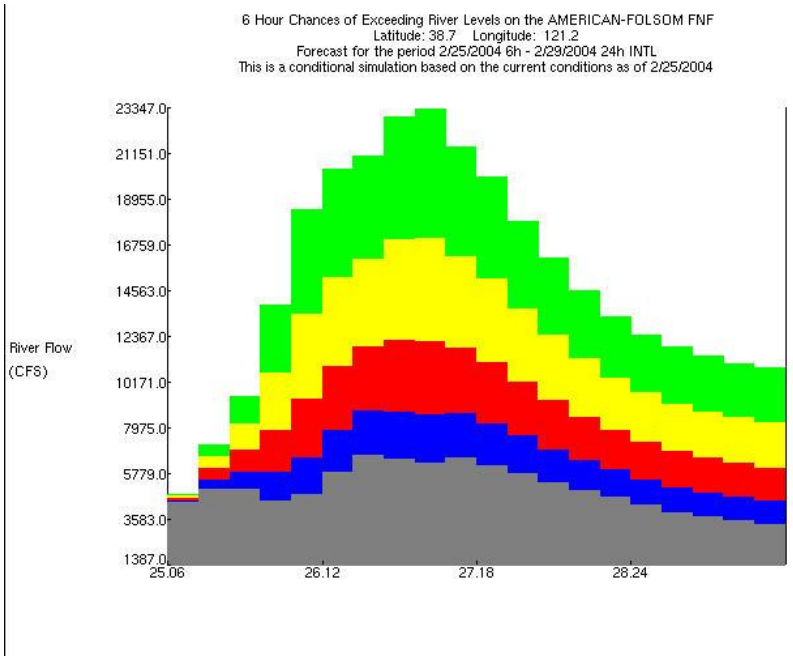
- **Accurately incorporate the impacts of reservoirs and diversions**
  - Reservoir models only approximate the actual operator decisions
  - Reliable information about diversions is rarely available
  - Significant impact on “actual” flows
  - Very important to many user groups



Ensemble Forecasting Challenge

- **Maintain coherence between deterministic and ensemble forecasts**



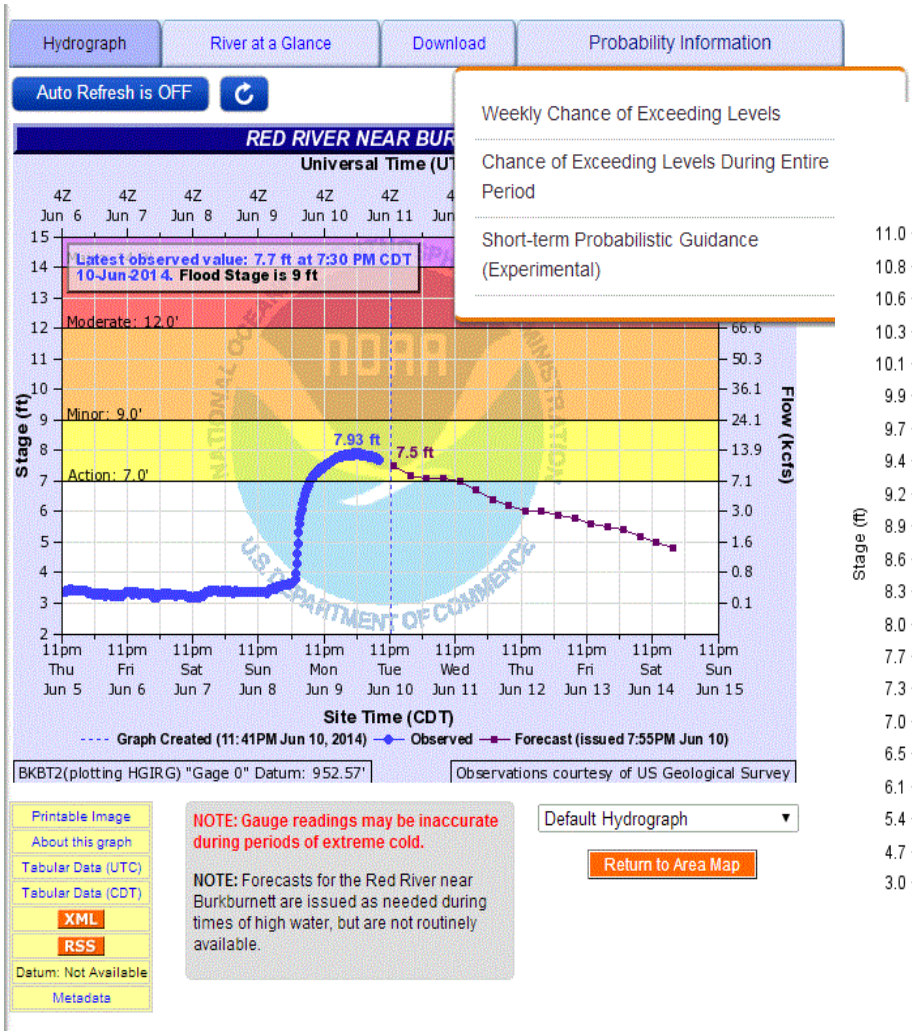


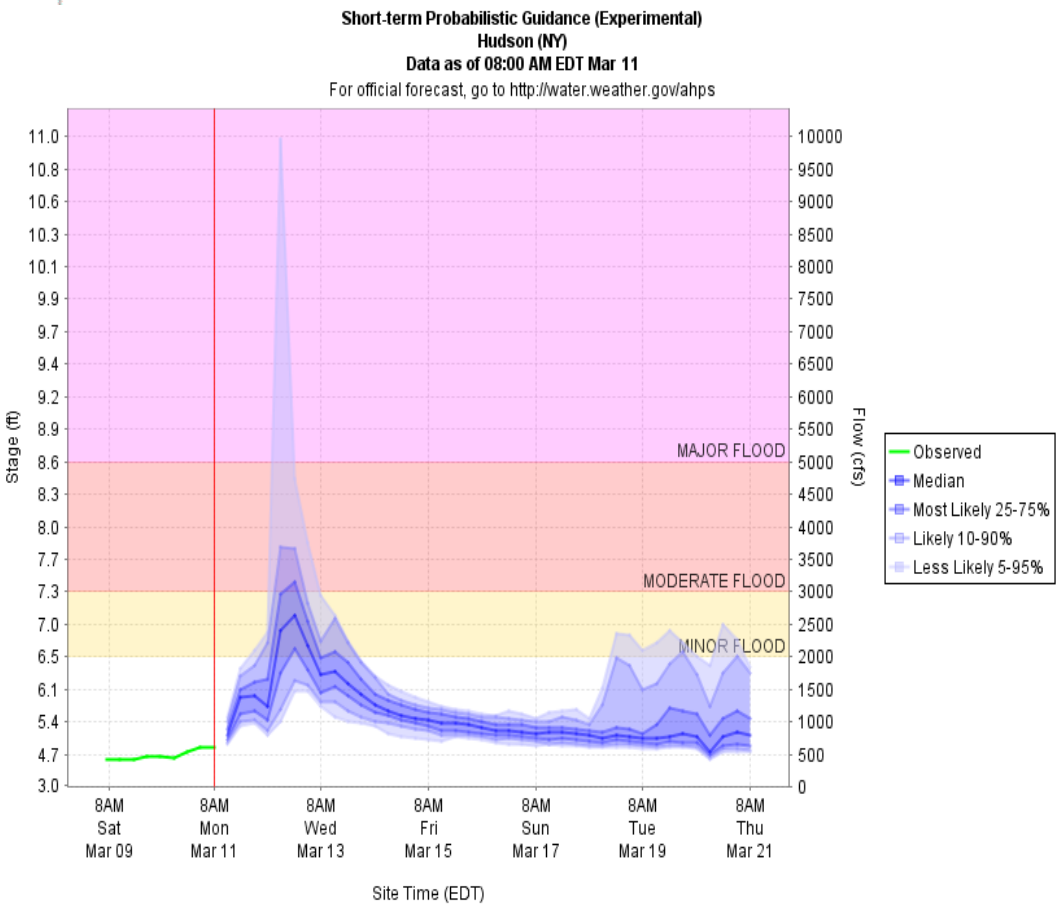
Ensemble Forecast Challenge of a different kind

- **Provide uncertainty information in a form and context that is <u>useful to our customers</u>**
  - Education and training
  - Context, validation and verification
  - Compatibility with decision support tools

- **Realizing the full utility of this information**
  - *Internal NWS customers (WFOs)*
  - *External partners and customers (Water Managers, USACE, EMs, local communities, public)*

New Experimental AHPS Ensemble Products





NWS Forecast Dissemination and Warning Process

RFC
Flood
Forecasts

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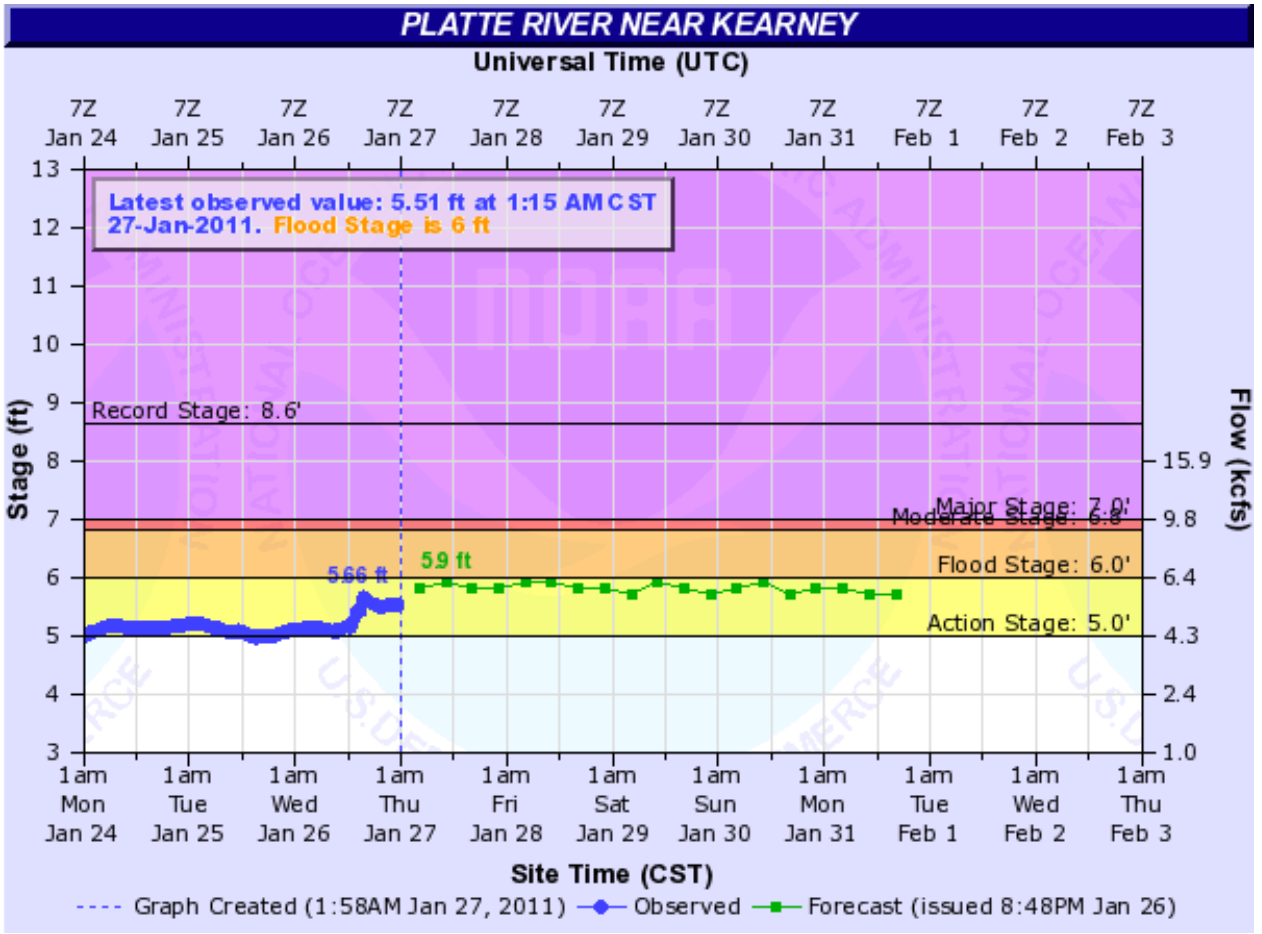
WFO
Product Generation
Software
* WARNGEN
* RIVERPRO

↓

Users



NATIONAL WEATHER SERVICE CENTRAL REGION SUPPLEMENT 02-2002
APPLICABLE TO NWSI 10-922

But probabilistic thinking exists

December 8, 2009

Operations and Services
Hydrologic Services Program, NWSPD 10-9
Weather Forecast Office Hydrologic Products Specification, NWSI 10-922

outlook and/or a watch. When issuing hydrologic products, the use of confidence levels should be similar to those used in other NWS Outlook/Watch/Warning products. The following are guidelines to assist the forecaster in the decision making process:

- Include flood potential information in the Hazardous Weather Outlook (HWO) for 30 % or greater chance of hazardous flooding in the 1 to 7-day time frame.
- Issue a Hydrologic Outlook for a 30 %-50% chance of flooding and/or where more detail is deemed necessary than what is stated in the HWO. The ESF is not mandatory if the information is adequately presented in the HWO.
- Issue a Flood Watch for a 50-80% chance of flooding.
- Issue a Flood or Flash Flood Warning for an 80% or greater chance of flooding that is expected to reach warning criteria (e.g., flood stage or fast-flowing water at least six inches in depth).
- Issue a Flood Advisory for an 80% or greater chance of flooding that is not expected to reach warning criteria but could cause significant inconvenience, and if caution is not exercised, could lead to situations that may threaten life and/or property.

Taking NWS to the Next Level

Impact-based Decision Support Services

- **IDSS has four elements:**
  - **Better understanding of societal impacts.**
  - **Making our information more relevant to decision makers.**
  - **Participating directly in decision making for those decisions fundamental to the role of government, especially the protection of life and property.**
  - **Counting on market forces to provide diverse decision-support services across the entire economy.**

What is needed for partners?

- **Demonstrating the skill/value in these forecasts**
  - Verification Information
  - Event specific
- **Communicating effectively**
  - Understandable
  - Enhanced formats
  - Data Services
- **Commitment to overcoming hurdles**
  - Policy
  - Legislative mandates
  - Bureaucracy
  - Entrenched process

Summary

- **NWS has an established practice of probabilistic forecasting at the long range, but there is much more potential in that information to be exploited**

- **At the short range, NWS is just beginning to really determine how best to use streamflow ensemble output**

- **The communication and process challenges may be as difficult as the technical challenges of producing reliable/skillful ensemble forecasts.**