Verifying Hydrologic Forecasts in the U.S. National Weather Service

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Outline

- Forecast Verification at NWS: needs and vision
- Hydrologic Products and Services
- River Forecast Verification System
- Ensemble Verification System (EVS)
  - Results for precipitation and streamflow ensembles
  - New graphics and measures
- Closing Remarks

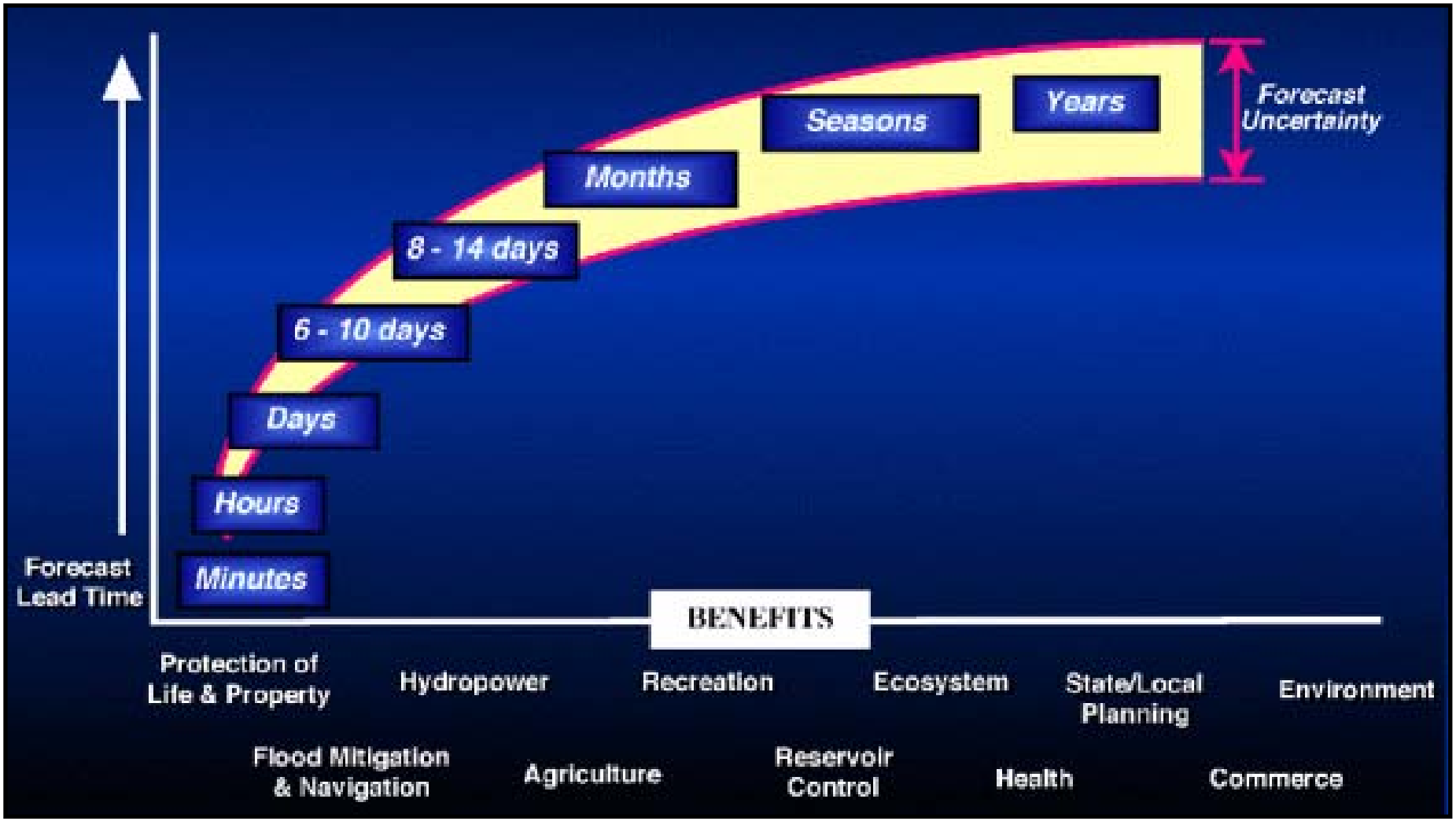
Forecast Verification at NWS

- **Needs:**
  - 1996: National Research Council stated verification of hydrologic forecasts was inadequate
  - 2006: Board on Atmospheric Sciences and Climate recommended NWS to expand verification of its uncertainty products and make it easily available to all users in near real time

- **Vision:**
  - Develop a comprehensive national system to verify hydrologic forecasts and guidance products which satisfy the needs of all users
  - Improve forecast services by analyzing sources of error and skill across the entire forecast process
  - Provide easy access to enhanced river forecast verification data to improve our scientific and operational techniques and services

Hydrologic Products and Services

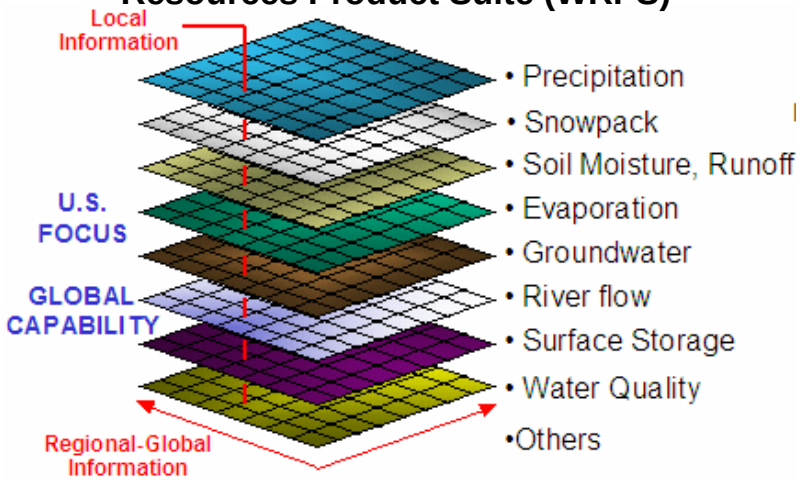
- Consistent probabilistic forecasts for all lead times & verification information



Hydrologic Products and Services

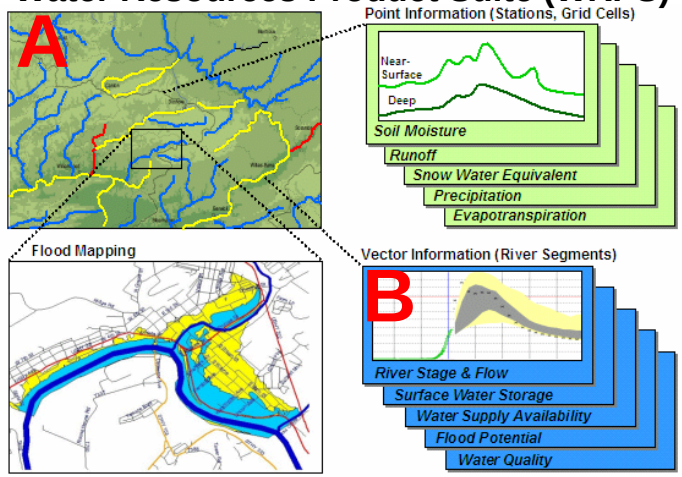
- Examples of ensemble graphical products

NWS-NDFD High-Resolution Gridded Water Resources Product Suite (WRPS)

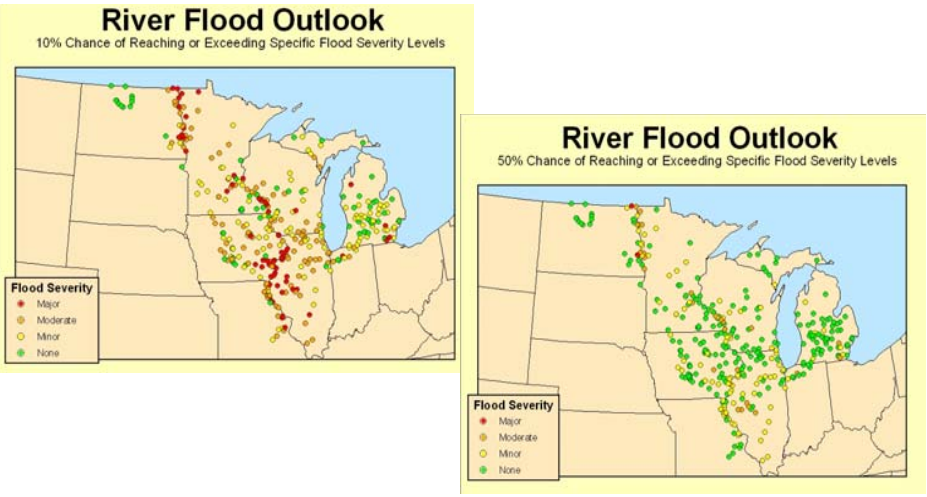


NWS-NDGD Gridded Uncertainty Product

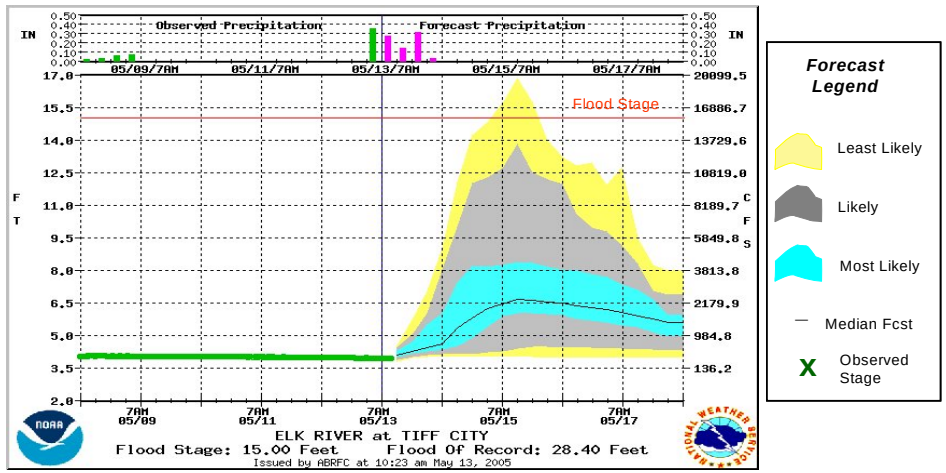
NWS-NDFD High-Resolution Geospatial Water Resources Product Suite (WRPS)



A River Flood Outlook Products

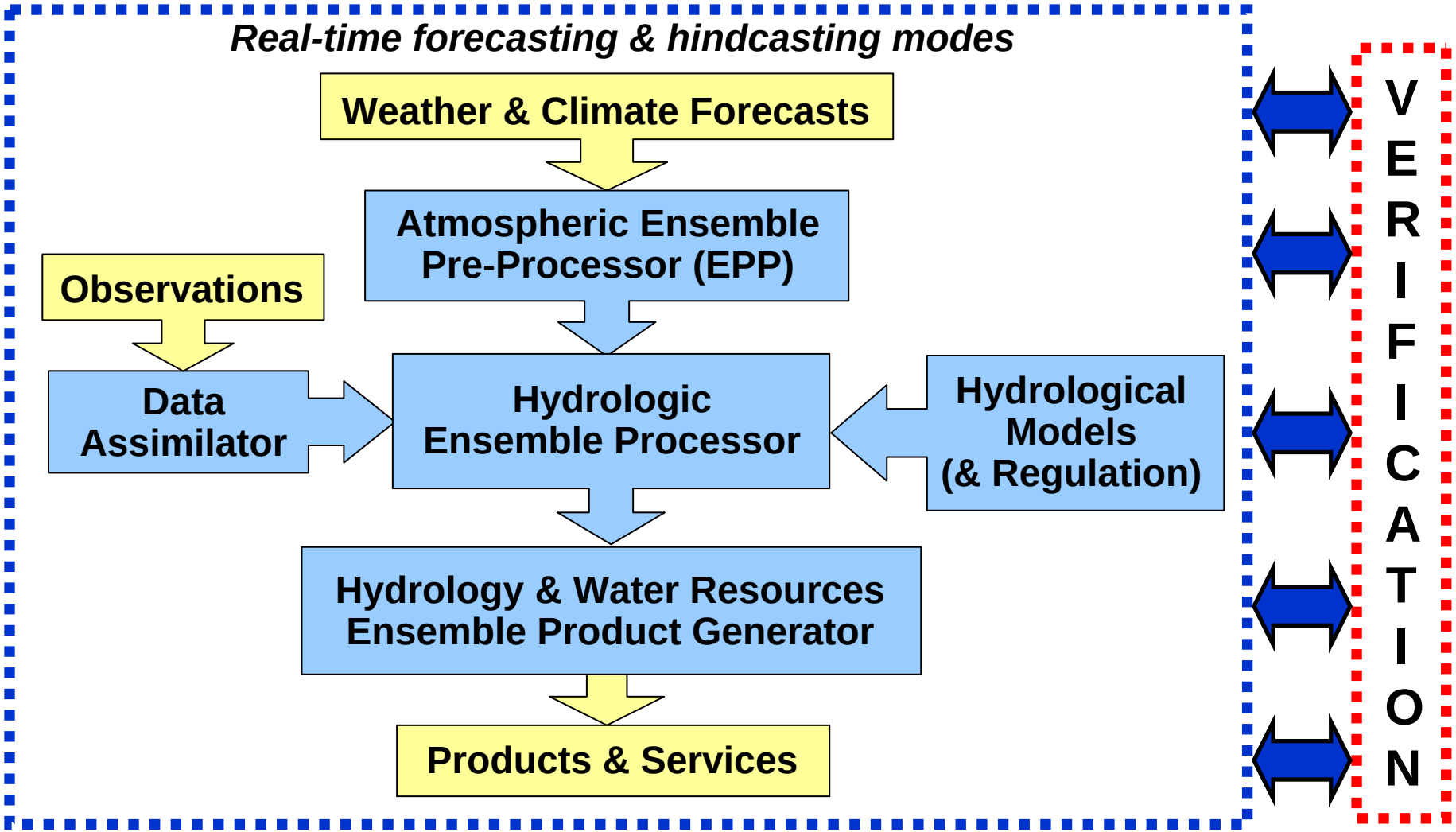


B Products for hydrometeorological inputs and hydrologic forecasts



Hydrologic Ensemble Prediction System

- Goal: to improve reliability and skill and to accurately account for uncertainties



River Forecast Verification System

- **Goals:**
  - Quantify quality of RFC forecasts and quality of forecast services
  - Monitor forecast quality over time
  - Monitor quality at various steps in the forecast process
  - Improve forecast quality
  - Assist prioritization of forecast system enhancements

- **Uses:**
  - Operational
  - Experimental/Research

- **Customers:**
  - Hydrologic forecasters
  - Scientists/Researchers
  - Hydrologic program managers
  - Emergency and water resources managers
  - Public

River Forecast Verification System

- **Components**
  - Logistical verification
  - Deterministic verification
  - Probabilistic verification

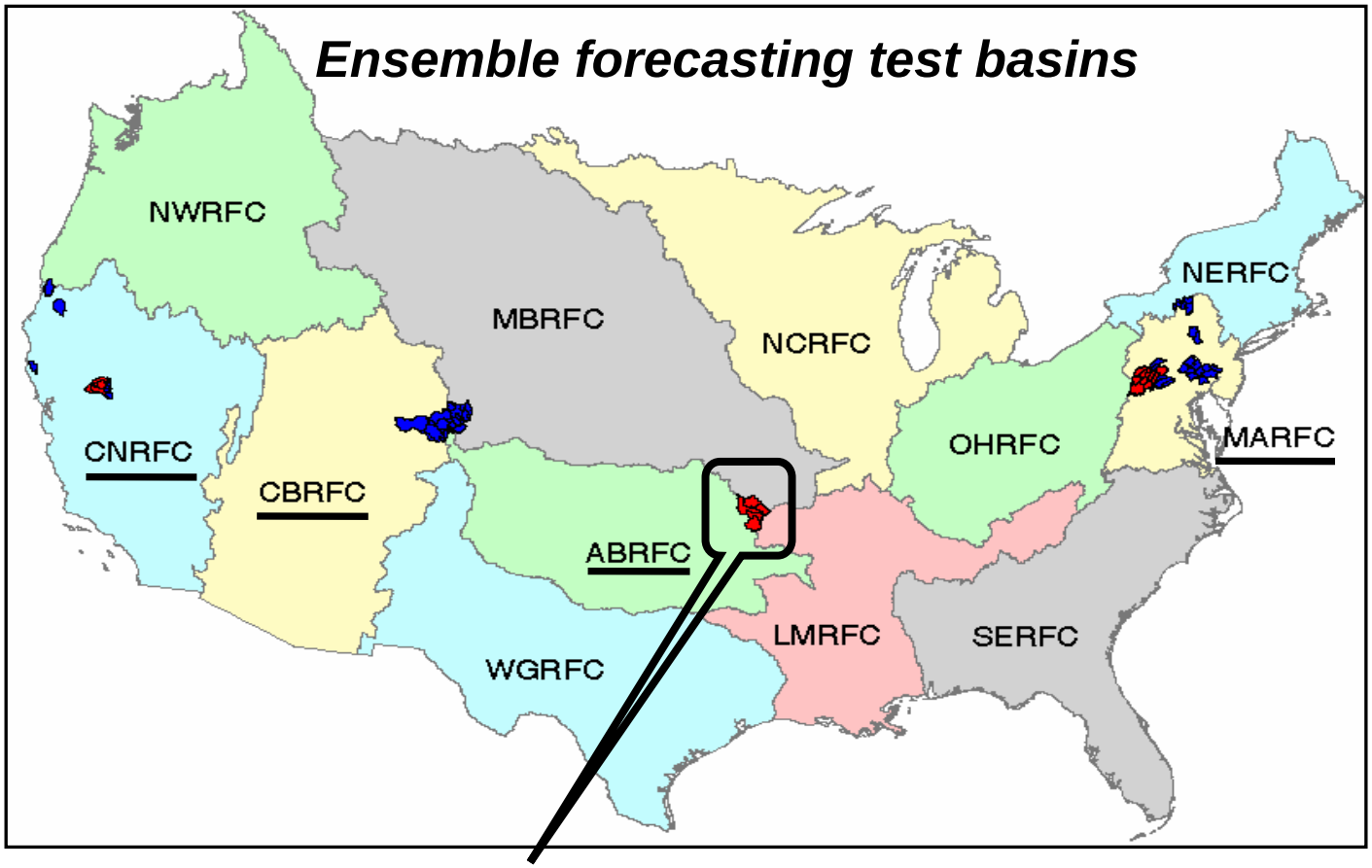
- **Verification System Capabilities**
  - **Data Archiving** (attributes for time, service, basin and events)
  - **Computing Metrics**
  - **Displaying Metrics** (graphics and reports)
  - **Disseminating Metrics and Data** (understand quality & usefulness of forecasts)
  - **Real Time Access to Metrics** (understand errors in recent forecasts and over long term)
  - **Error Analysis** (including hindcast experiments)
  - **Performance Measure Tracking** (level of success)

Ensemble Verification System (EVS)

- A prototype application intended for systematic verification of all the components of the ensemble prediction system:
  - Verification of ensemble hindcasts/forecasts for inputs (precipitation, temperature) and outputs (streamflow)
  - Supporting application: Ensemble Hindcaster for systematic hindcasting (re-forecasting) based on operational forecasting system

- EVS consists of
  - A suite of data processing and science algorithms that:
    - processes observed and hindcast/forecast data
    - calculates a suite of verification statistics
  - A suite of R scripts for graphical display of verification statistics and data
    - scatter plots
    - deterministic and probabilistic verification metrics
  - A Java user interface

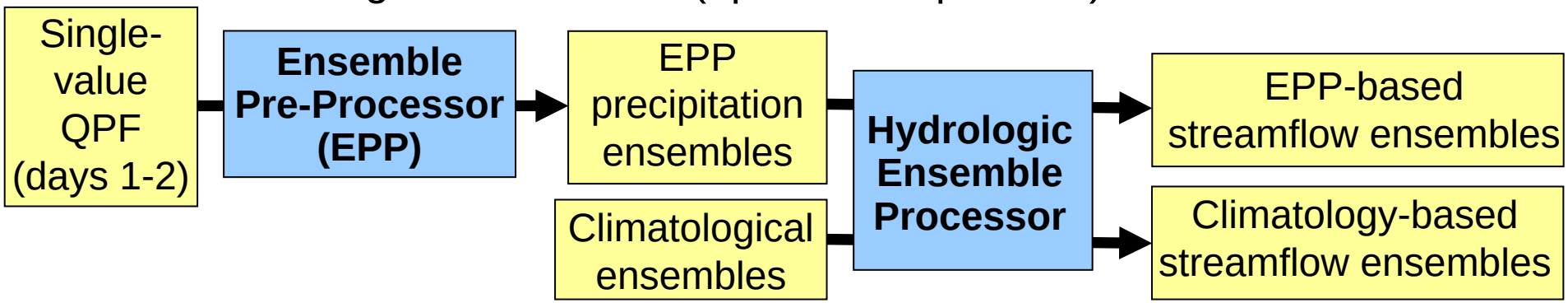
EVS Results: Test Areas at the NWS River Forecast Centers (RFC)



- Verification study for 5 test basins within ABRFC area:
  - Ensemble hindcasts for precipitation and streamflow for 14 lead days
  - Verification period: 03/2003 - 08/2005 (890 events at 24-hr time step)

EVS Results: Forecasts to be verified

- Precipitation forecasts generated by Ensemble Pre-Processor:
  - Single-value (i.e. deterministic) forecast has additional skill from human forecasters, particularly in Day 1
  - Precipitation ensembles from NWP have significant biases in mean and spread
  - Goal of Ensemble Pre-Processor is to produce precipitation ensembles that are unbiased and that reflect additional skill
    - A practical, "observation-driven" approach for ensemble generation (see Schaake *et al.* 2007 in HESS)
- Streamflow forecasts generated from:
  - EPP precipitation ensembles
  - Climatological ensembles (operational process)

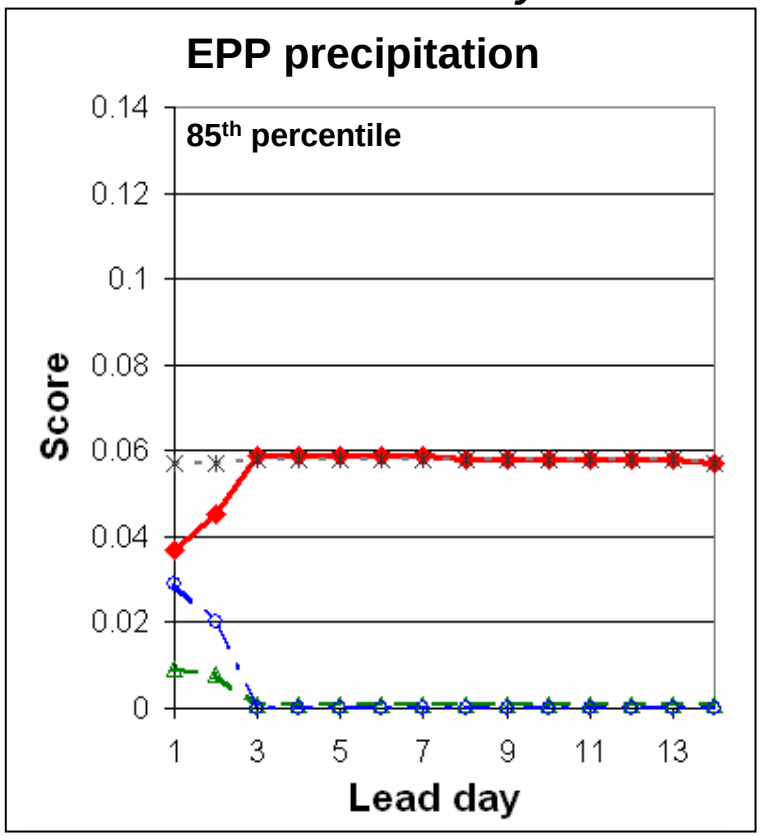


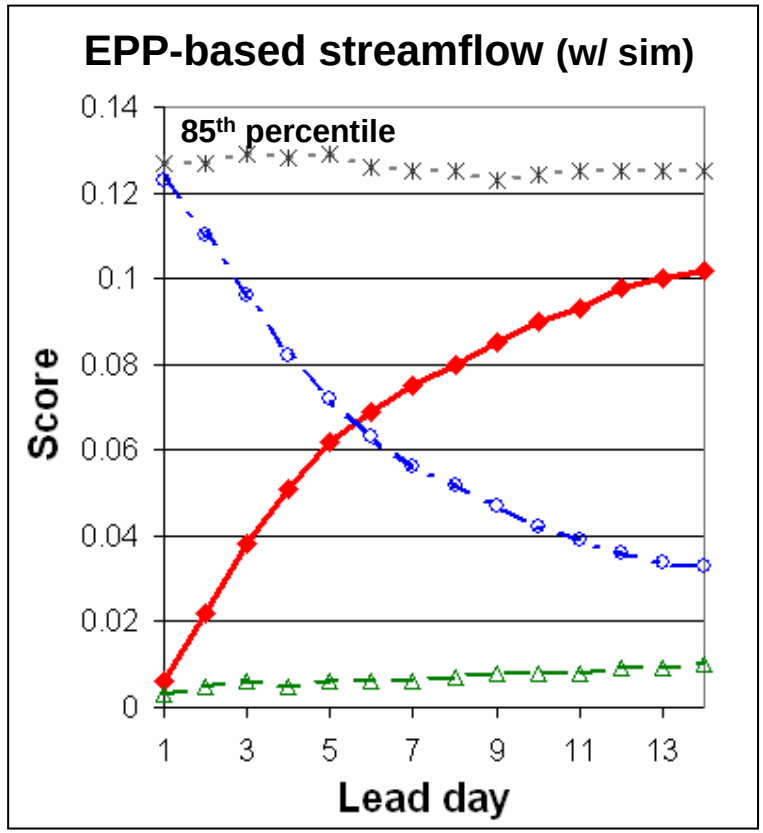
EVS Results: Brier Score

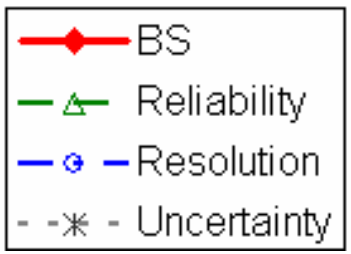
- Brier Score (mean squared probability error):
  - EPP precipitation ensembles
  - EPP-based streamflow ensembles compared to simulated flows to evaluate only impact of input error

BS = Reliability – Resolution + Uncertainty

Perfect score: BS=0



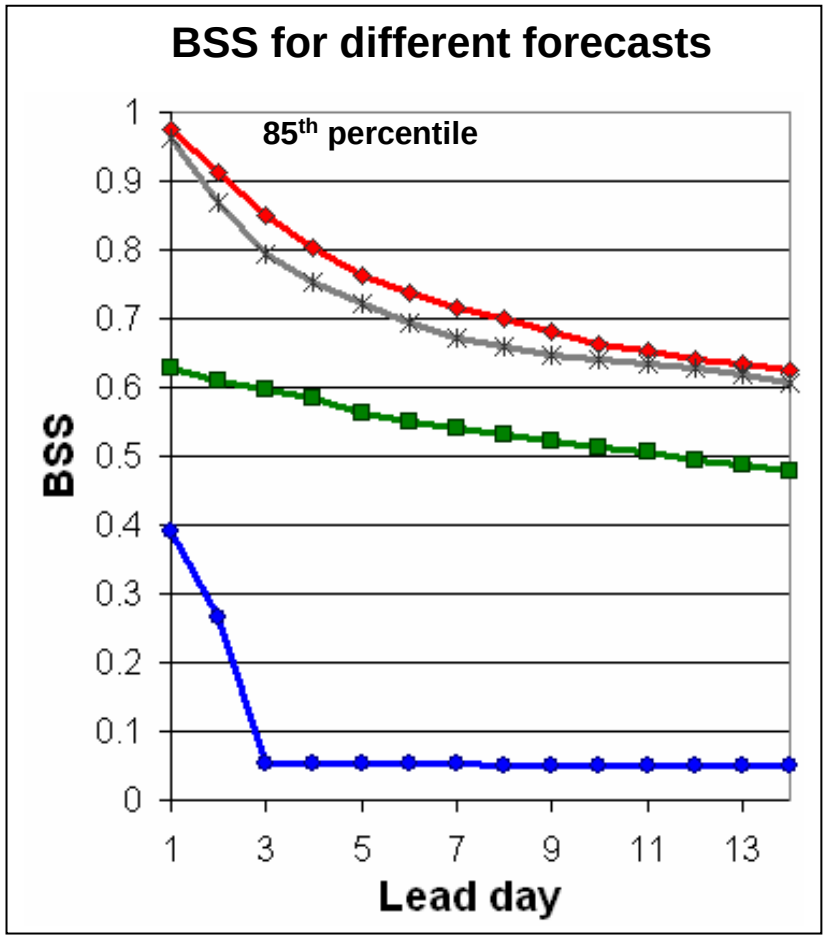




EVS Results: Brier Skill Score

- Brier Skill Score (w/ climatology as reference):
  - EPP precipitation ensembles
  - EPP-based streamflow ensembles compared to simulated flows
    -> input error
  - EPP-based streamflow ensembles compared to observed flows
    -> input and hydrologic errors
  - Climatology-based streamflow ensembles compared to simulated flows
    -> benefits from EPP

Perfect score: BSS=1



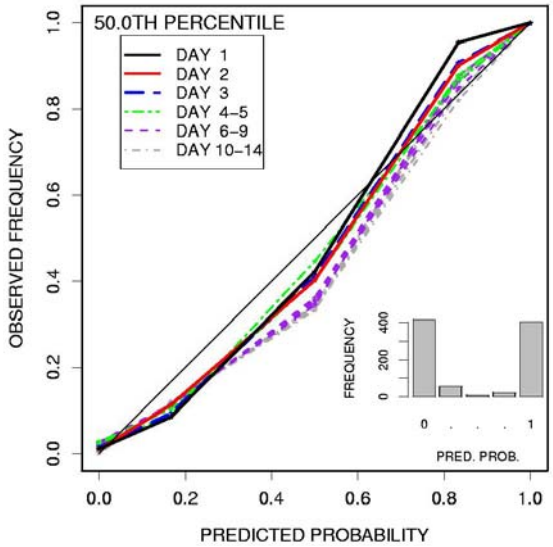
EVS Results: Reliability Diagram

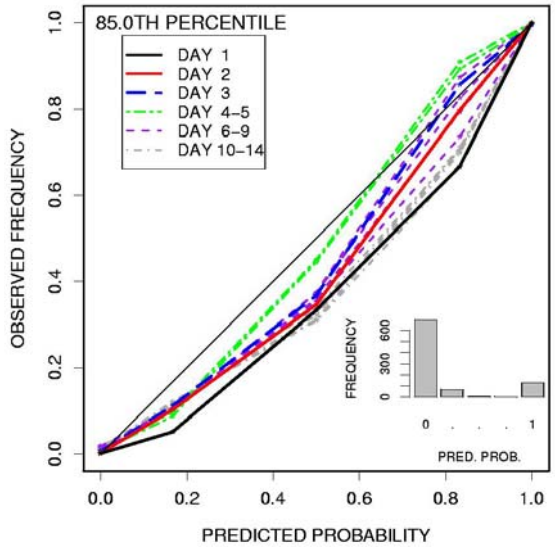
Reliability Diagram
(agreement between forecast probability and mean observed frequency)

Histogram for day 1

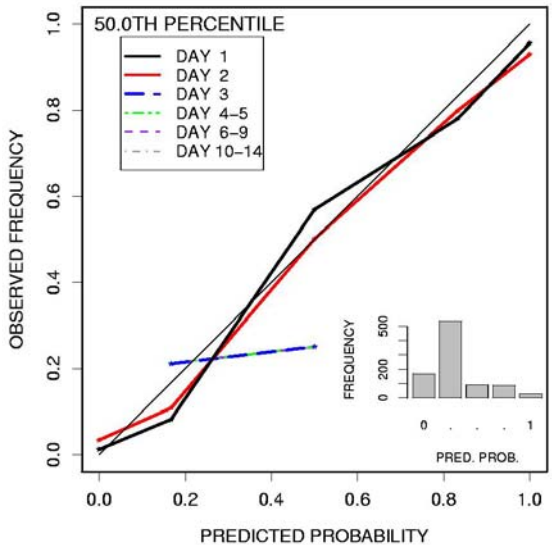
Deviation from diagonal indicates conditional bias

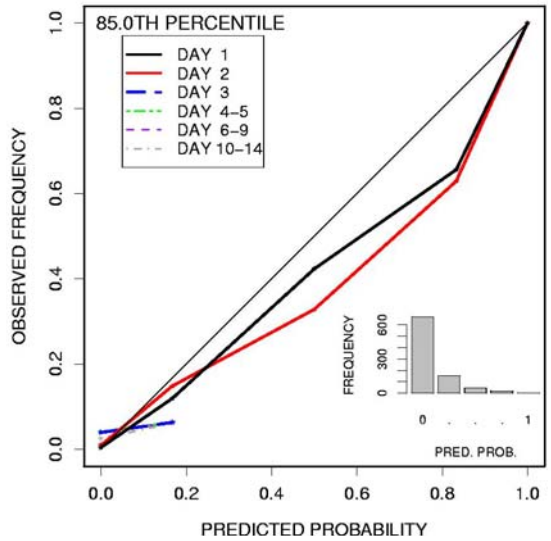
Streamflow forecast verification with simulated flows to assess:
- impact of input error
- benefits of using Ensemble Pre-Processor





EPP-based flow ensembles **(w/ sim)**





EPP precipitation ensembles

EVS Results: ROC

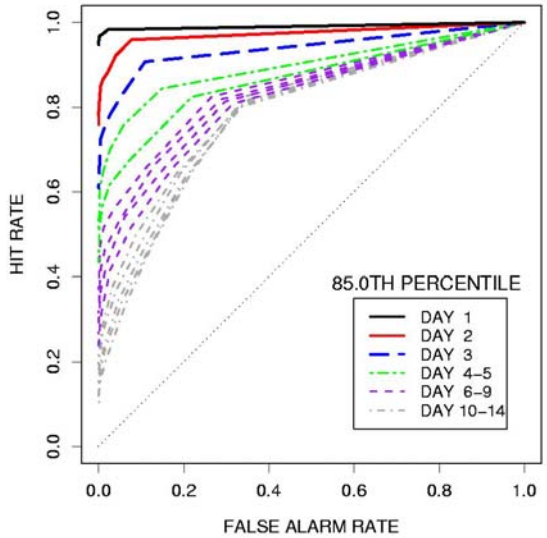
Relative Operating Characteristic (discrimination)

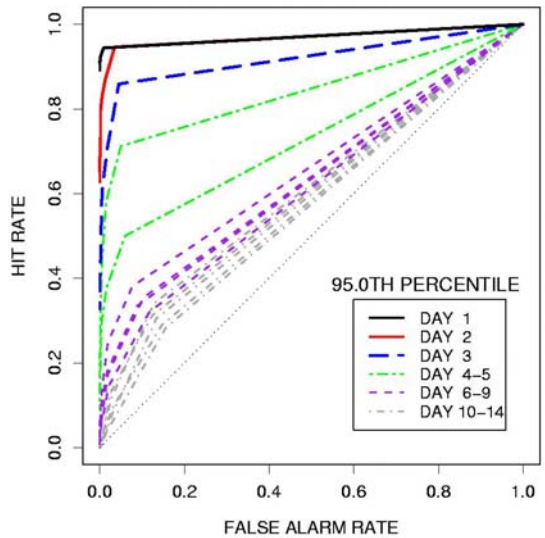
(with 10 probability thresholds)

Perfect scores:
HR = 1 and FAR = 0

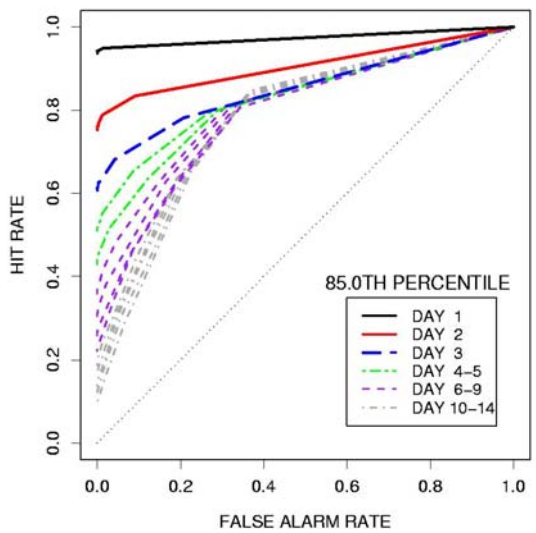
Diagonal: no skill

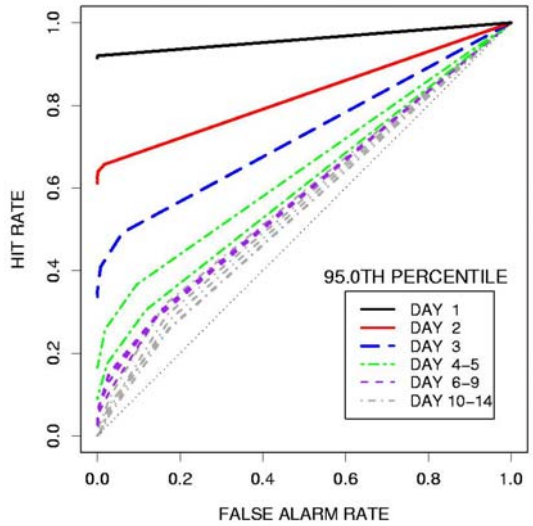
Streamflow forecast verification with simulated flows to assess:
- impact of input error
- benefits of using Ensemble Pre-Processor





EPP-based flow ensembles **(w/ sim)**

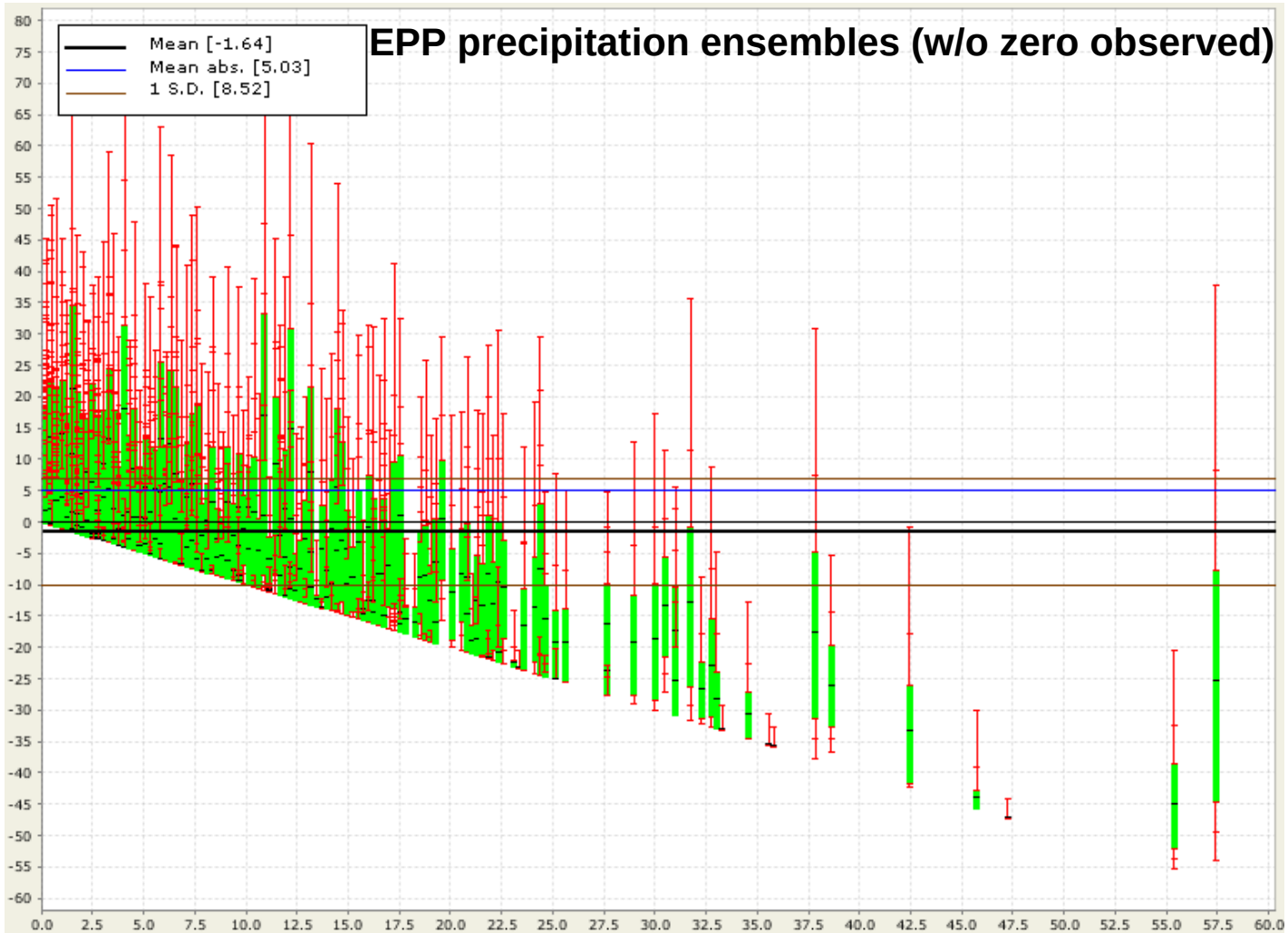


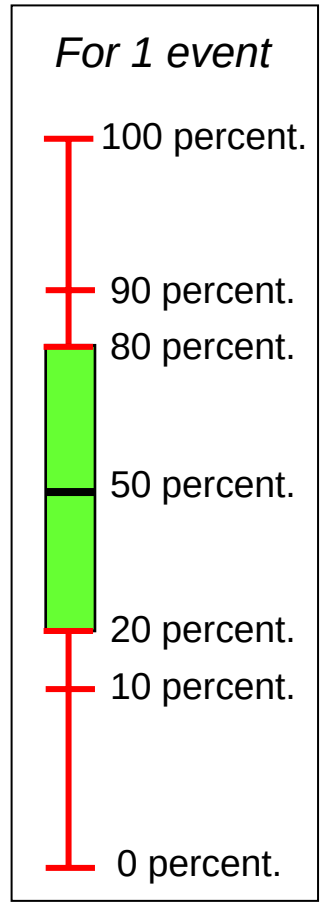


Climatology-based flow ensembles

EVS: New Verification Graphics

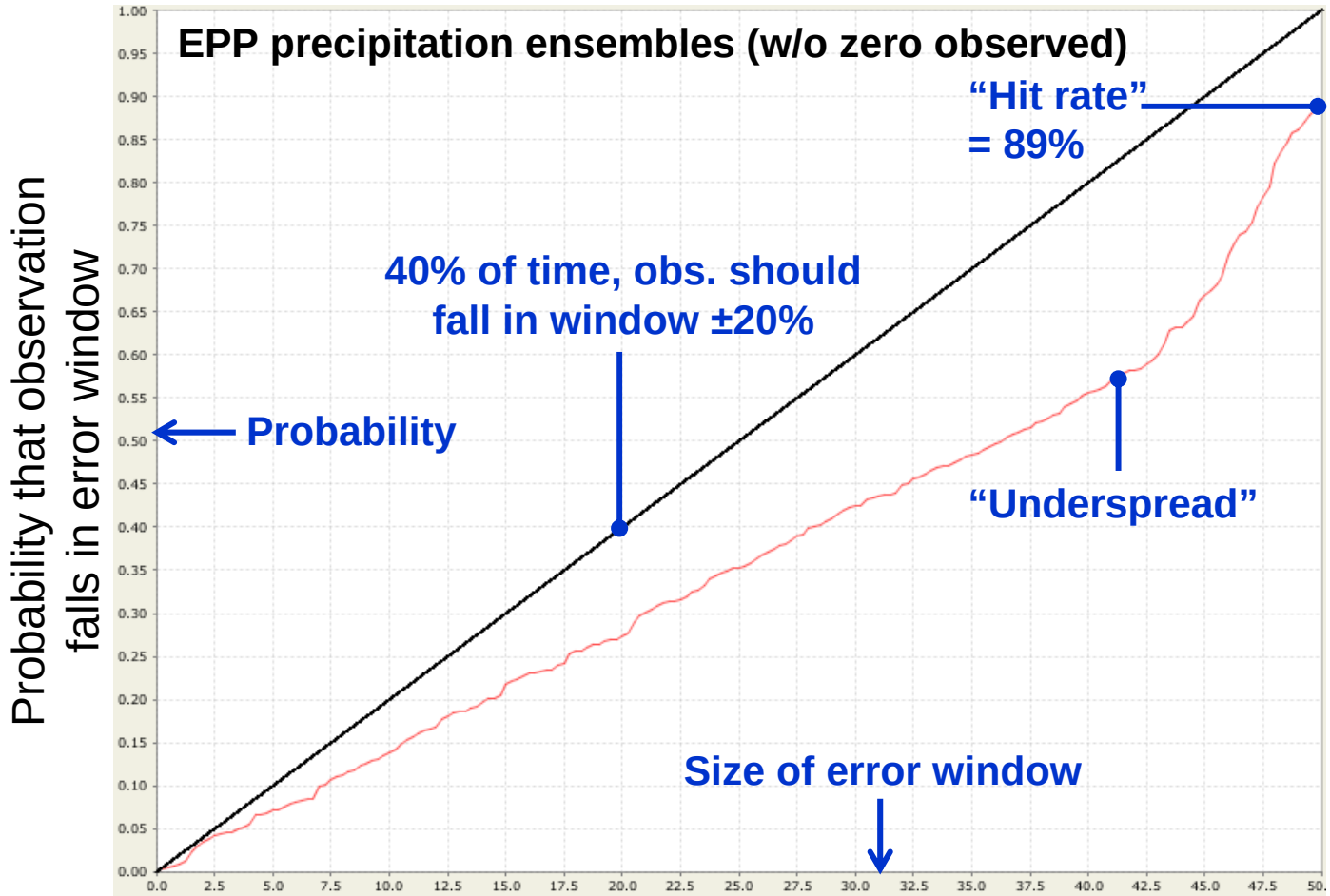
Modified box-and-whisker plot: marginal distribution of forecast error (x_{ens} - x_{obs}) for each event

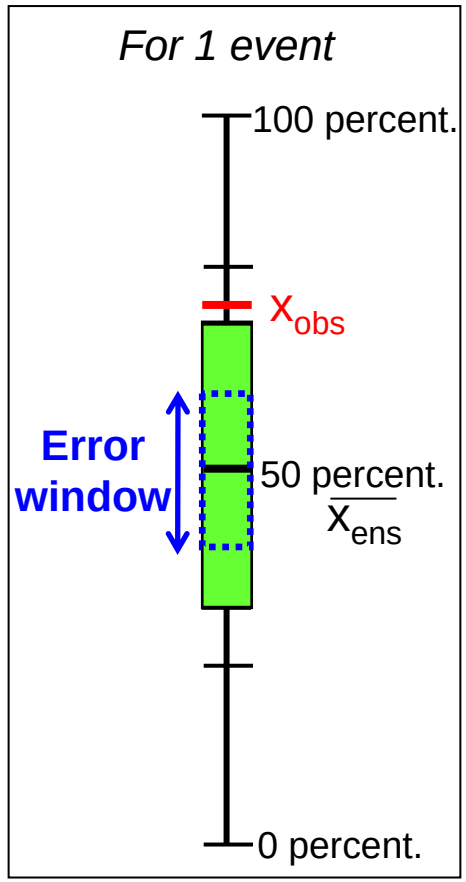




EVS: New Verification Measures

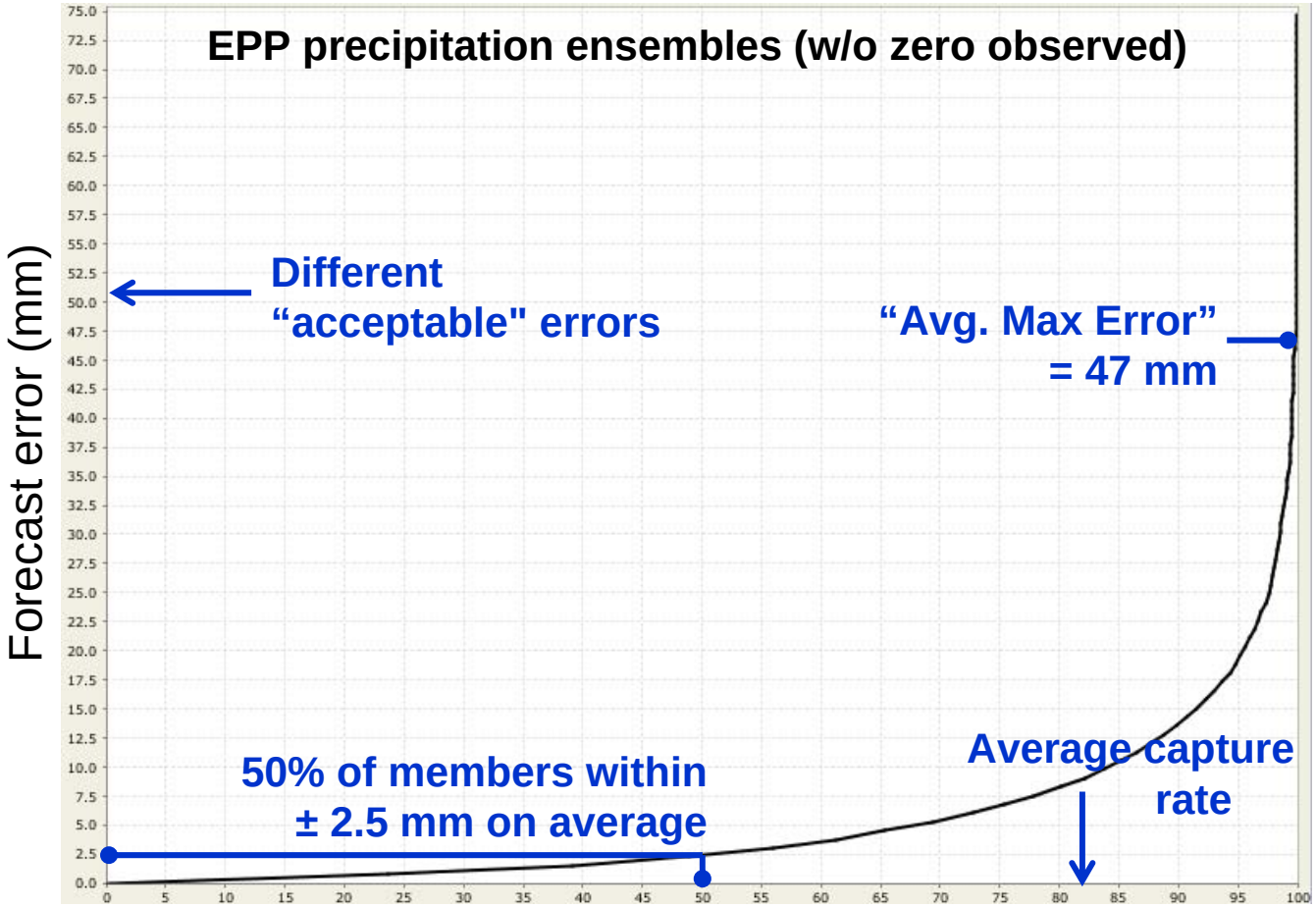
Cumulative Talagrand Plot: probability that observation falls in error window around median of probabilistic forecast

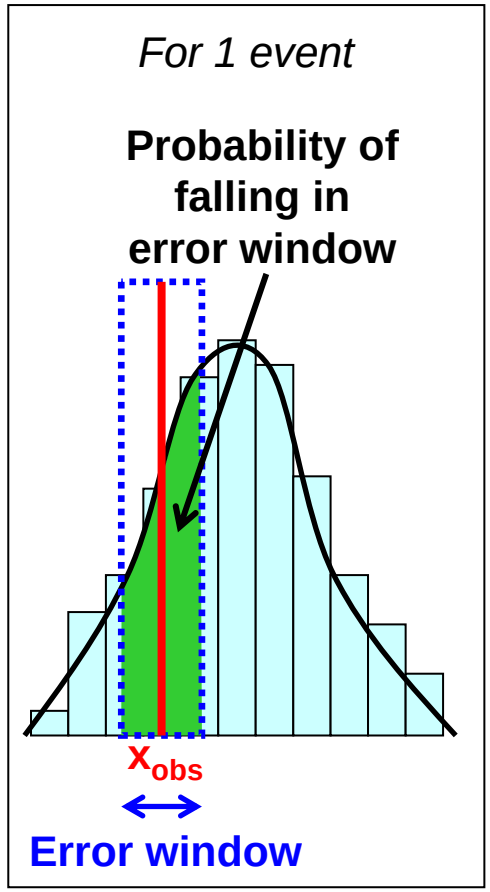




EVS: New Verification Measures

Average Capture Rate Plot: probability that ensemble members fall in error window around observation, averaged over time (mean of Wilson (1999) score)





Closing Remarks

- Hydrologic ensemble verification is relatively new
  - Develop new or adapt existing verification metrics that are easily understandable and informative for decision making

- Hydrologic forecasts are subject to many different sources of uncertainty (forcing inputs, initial conditions, models, etc.)
  - Identify and quantify uncertainties at every step of forecasting system (with hindcasting capabilities)

- Closer interdisciplinary collaborations (e.g. HEPEX) will help maximize the utility of weather and climate forecasts in hydrology and water resources applications
  - Communicate both meteorological and hydrologic uncertainties to the users for better decisions

Thank you

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