Short-Term Ensemble Research and Development (R&D) and Research-to-Operations (RTO) Plan
Draft (Nov 29, 2006)

Presented by D.-J. Seo

Hydrologic Ensemble Prediction Group
Hydrologic Science and Modeling Branch
Hydrology Laboratory
Office of Hydrologic Development
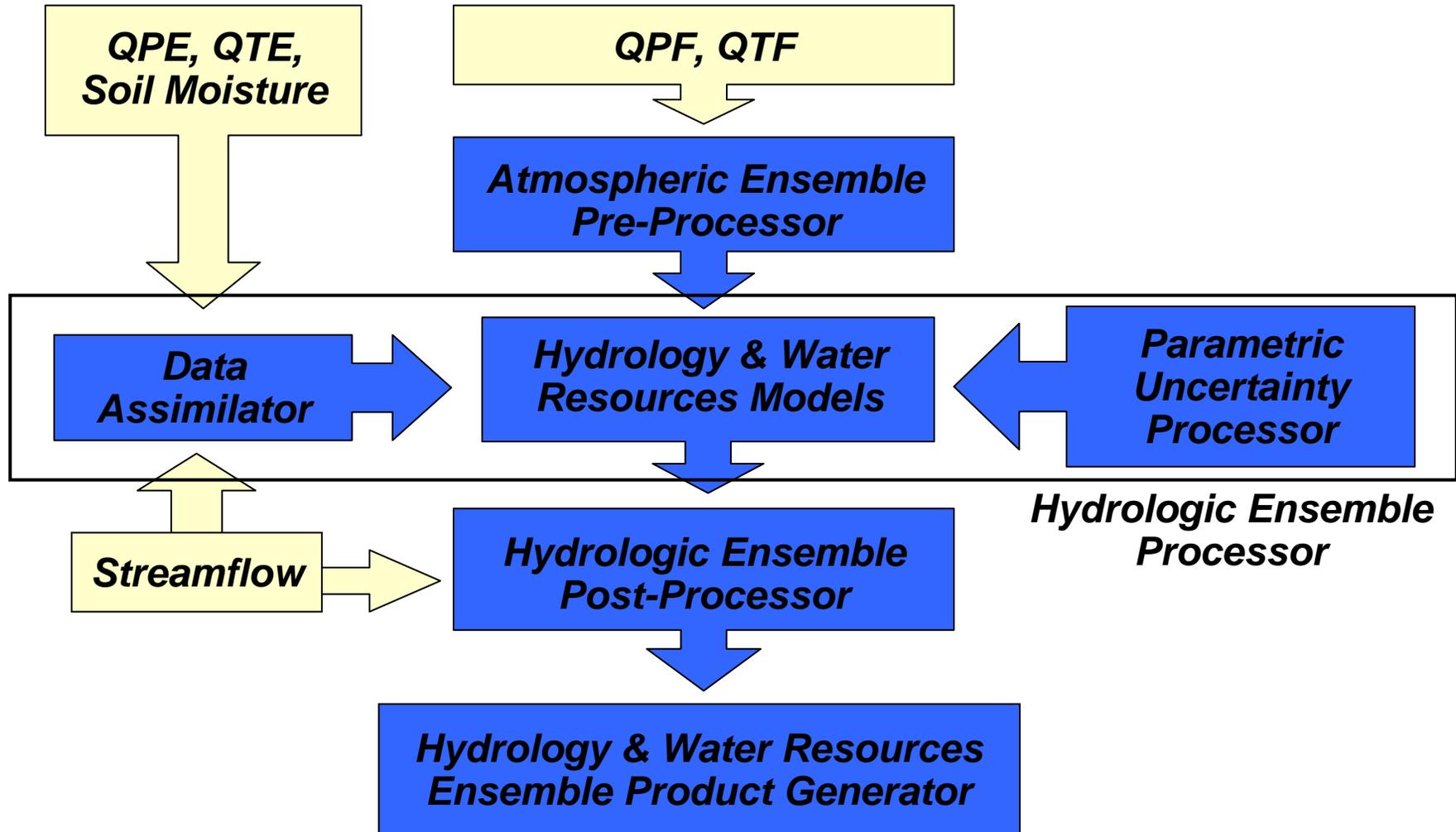NOAA/National Weather Service

Acknowledgments

- AHPS
- CPPA (Jin Huang, Program Manager)
- DOH Science Steering Team (DSST)
- AB-, CB-, CN-, MA-, WGRFCs, and WR
- Pedro Restrepo
- John Schaake
- Ken Mitchell
- Zoltan Toth
- Many other collaborators

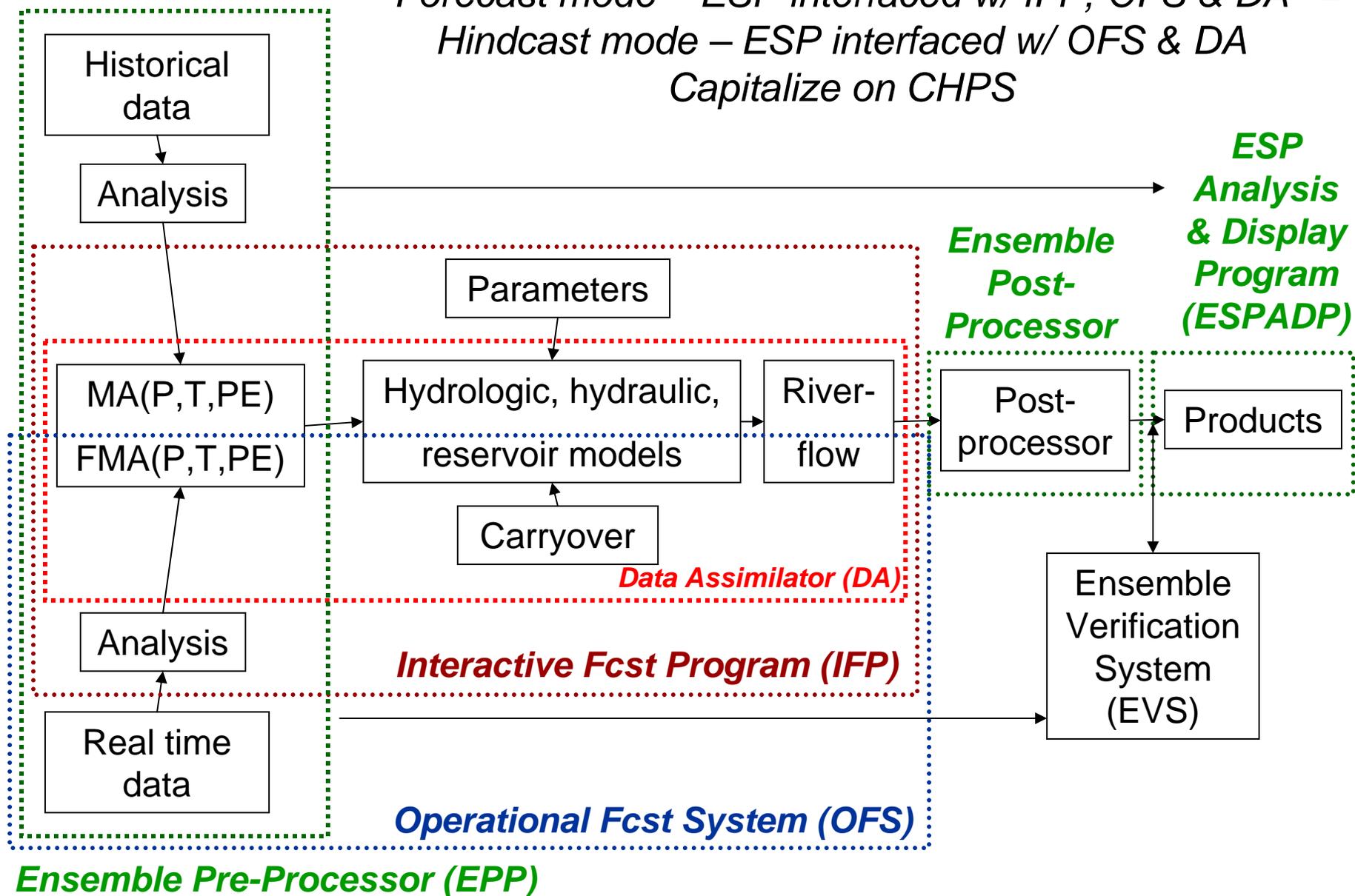# Elements of a Hydrologic Ensemble Prediction System

Targeted Ensemble forecast system

Forecast mode – ESP interfaced w/ IFP, OFS & DA
Hindcast mode – ESP interfaced w/ OFS & DA
Capitalize on CHPS

Historical data

Analysis

ESP Analysis & Display Program (ESPADP)

Parameters

Ensemble Post-Processor

MA(P,T,PE)
FMA(P,T,PE)

Hydrologic, hydraulic, reservoir models

River-flow

Post-processor

Products

Carryover

Data Assimilator (DA)

Analysis

Interactive Fcst Program (IFP)

Real time data

Ensemble Verification System (EVS)

Operational Fcst System (OFS)

Ensemble Pre-Processor (EPP)

Examples of STE graphical products

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

- Precipitation
- Snowpack
- Soil Moisture, Runoff
- Evaporation
- Groundwater
- River flow
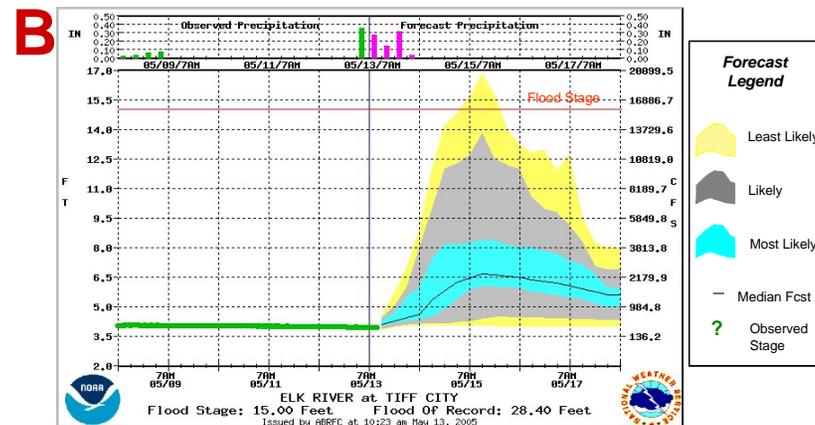- Surface Storage
- Water Quality
- Others
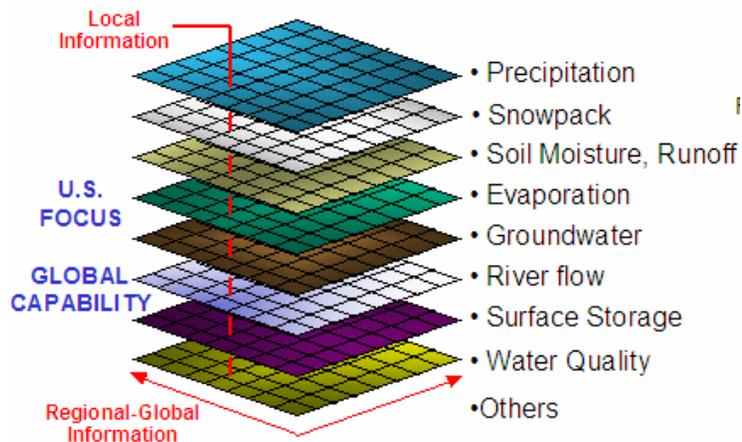
NWS-NDGD gridded uncertainty product

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

A — Point Information (Stations, Grid Cells)
Near-Surface, Deep — Soil Moisture, Runoff, Snow Water Equivalent, Precipitation, Evapotranspiration

Flood Mapping

B — Vector Information (River Segments)
River Stage & Flow, Surface Water Storage, Water Supply Availability, Flood Potential, Water Quality

A — River Flood Outlook

Flood Severity: Major, Moderate, Minor, None

B

Forecast Legend
- Least Likely
- Likely
- Most Likely
- Median Fcst
- ? Observed Stage

ELK RIVER at TIFF CITY
Flood Stage: 15.00 Feet   Flood Of Record: 28.40 Feet
Issued by ABRFC at 10:23 am May 13, 2005

Same as B above , but for hydrometeorological forcings

Seamless probabilistic forecasts for all lead times
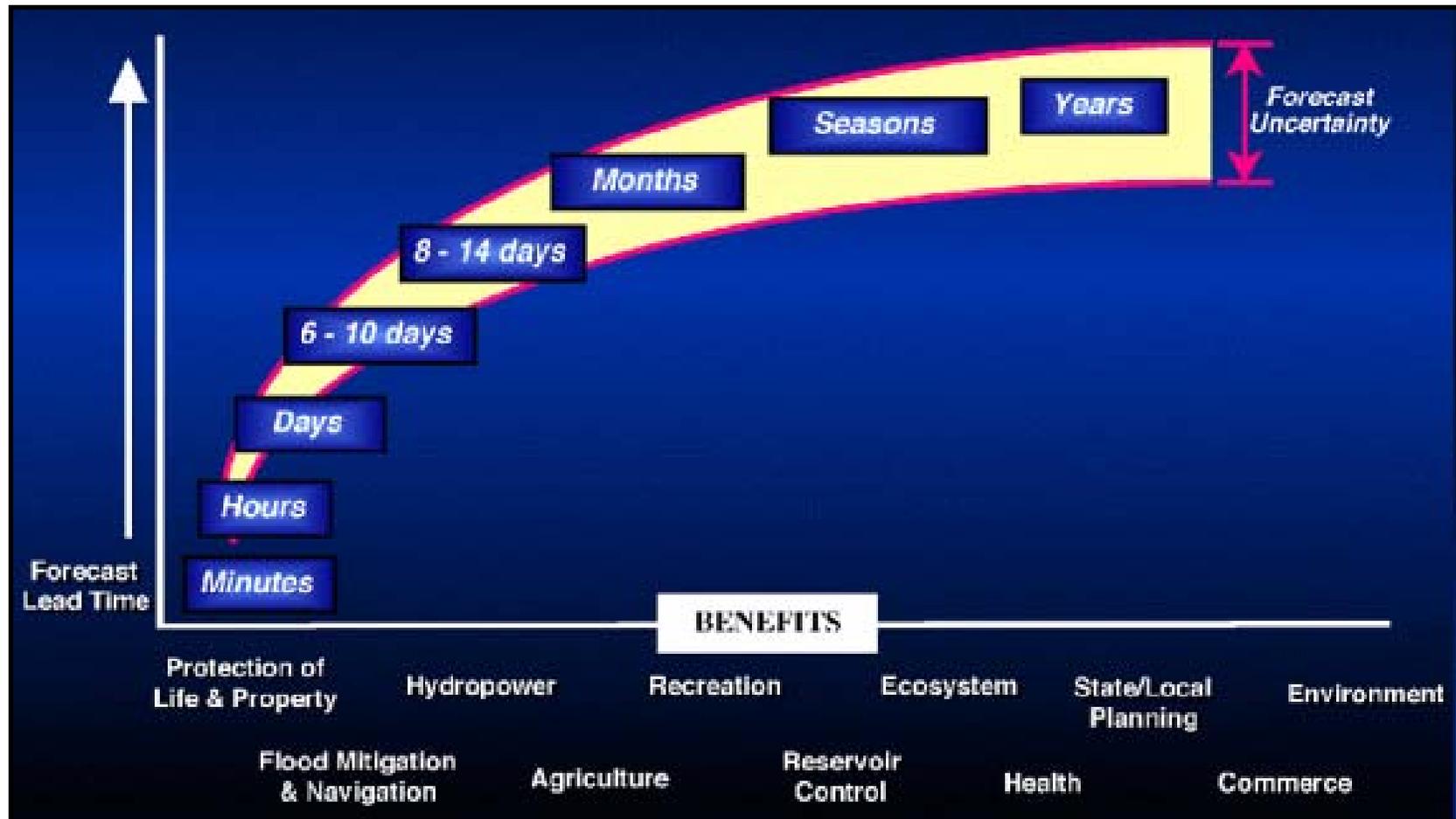
Current Ensemble Pre-Processor

- Short-range ensembles conditioned on HPC/RFC single-value forecasts (Schaake et al., submitted to HESS)

- Medium-range ensembles conditioned on ensemble mean from frozen version of NCEP Global Forecast System (GFS) (Schaake et al., submitted to HESS)

- Climate adjustment of historical ensembles based on CPC outlook (i.e. probability shift) products (Perica et al. 1999)

- Climatology distribution re-sampling to better-estimate true climatological distribution

Ensemble Pre-Processor

HPC/RFC QPF & QTF	→	RFC Subsystem	→	Ensembles out to Day 5
GFS ensemble mean forecast	→	GFS Subsystem	→	Ensembles out to Day 14	→ Blender →	Blended ensembles out to a year
CPC outlook forecast	→	Probability Adjustment	→	Ensembles out to a year
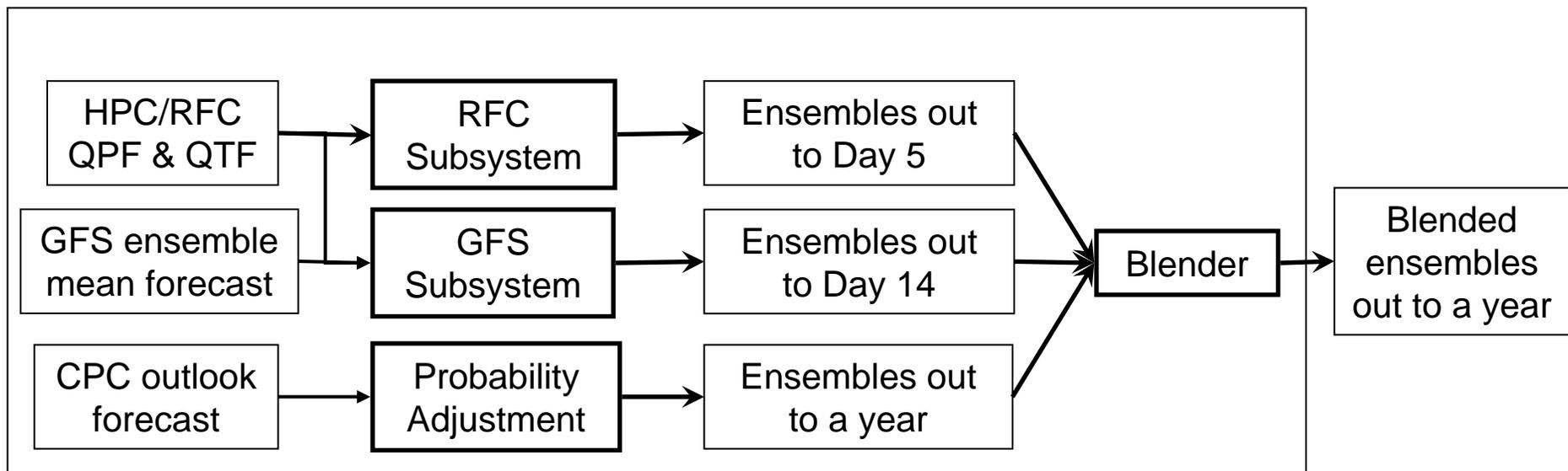
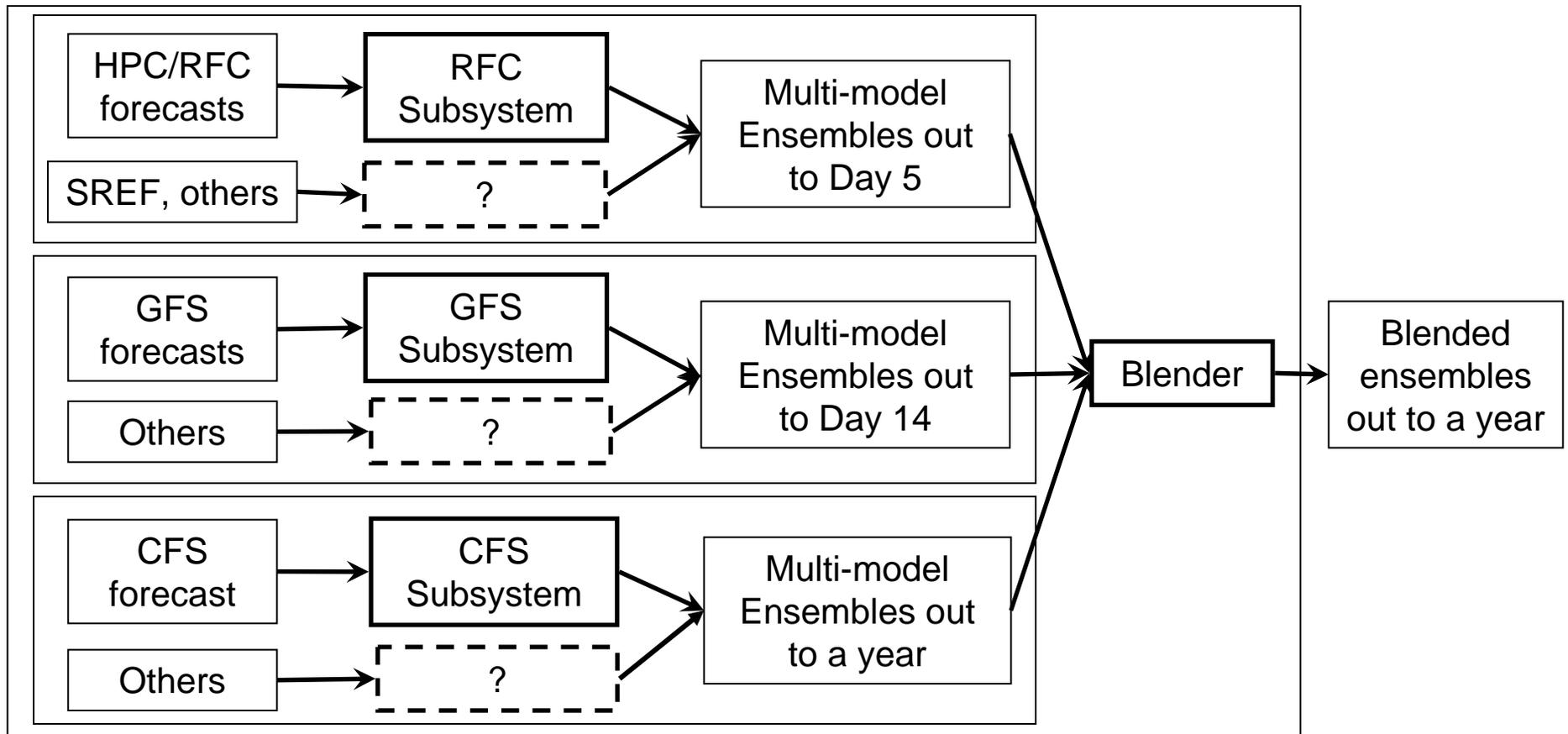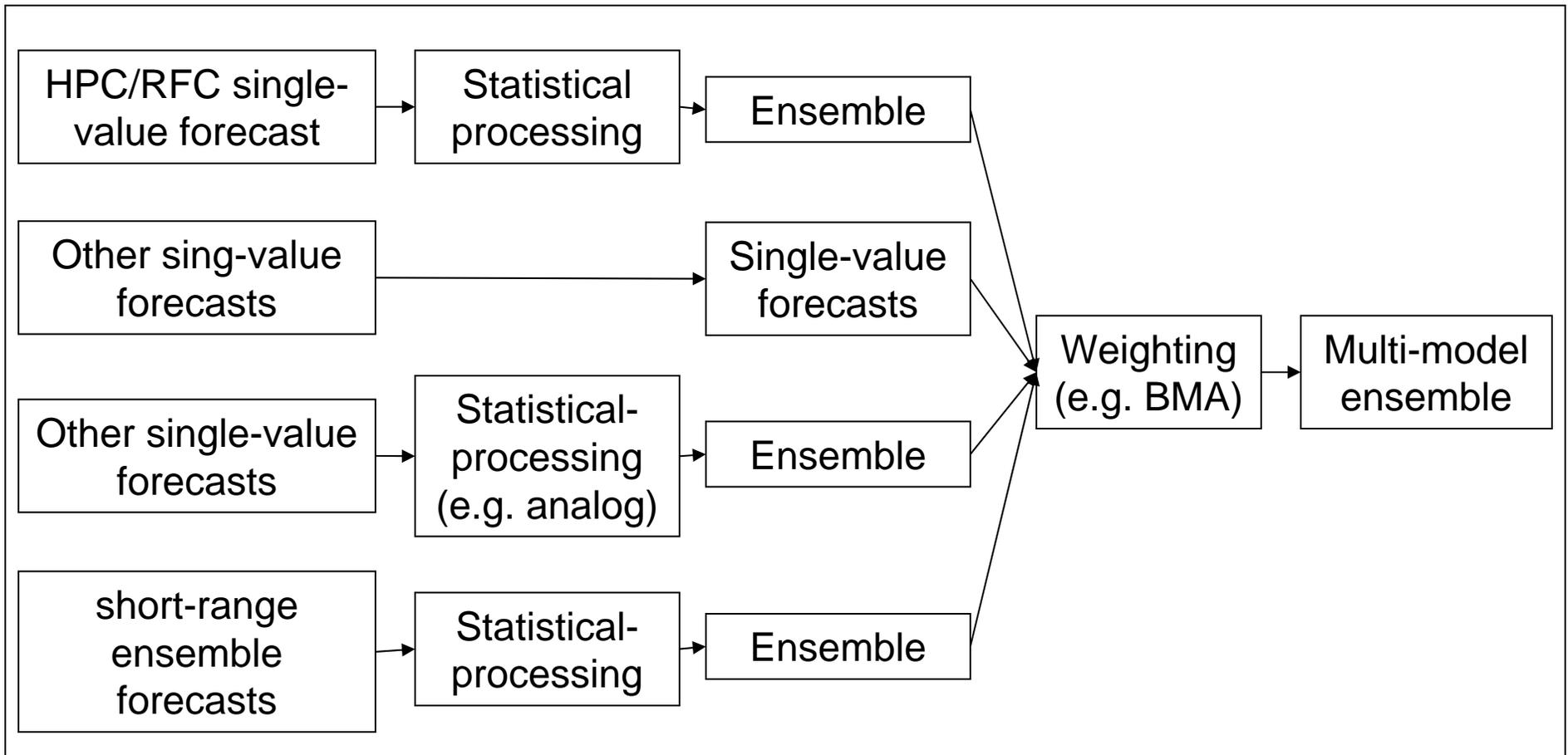# Planned Ensemble Pre-Processor

- To comprise RFC, GFS and CFS Subsystems as basic capabilities for generation of short-, medium and long-term ensembles
- To bring in additional forecasts and sources of information
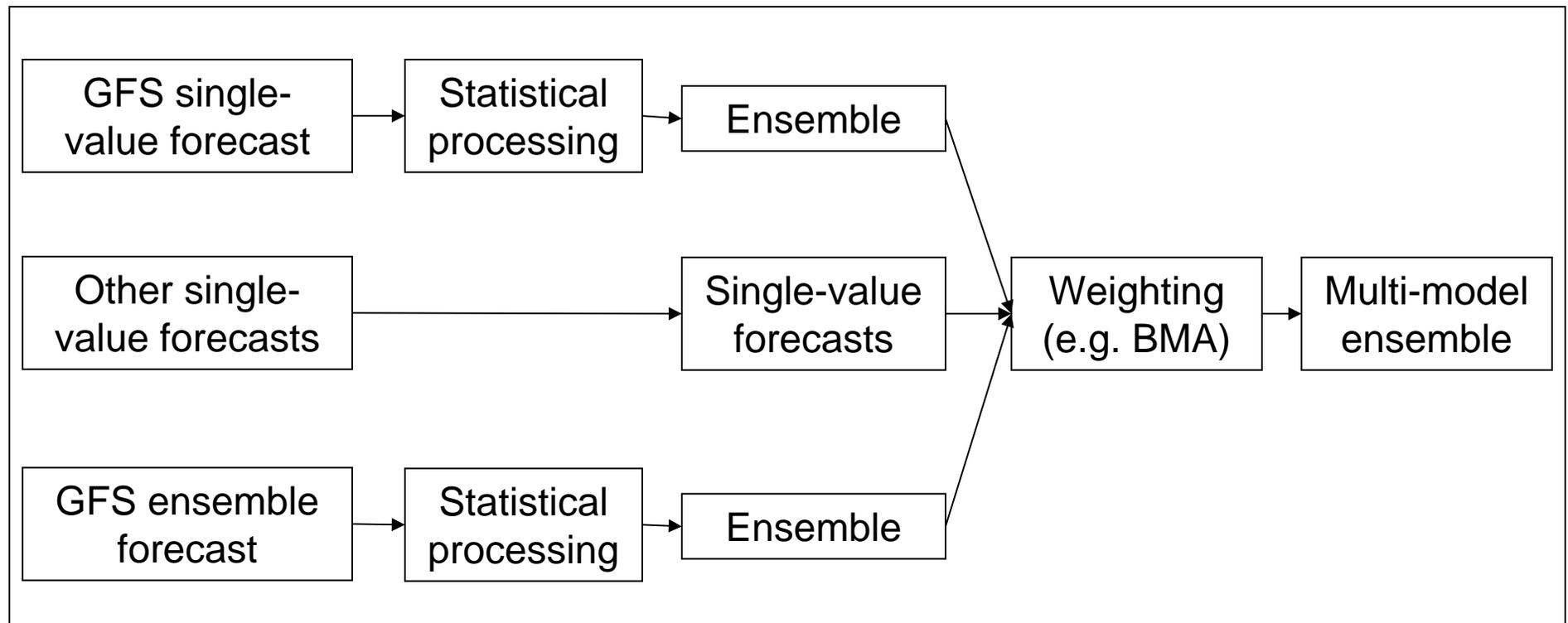
Ensemble Pre-Processor

```
┌──────────────────────────────────────────────────────────────────────────┐
│  ┌────────────────────────────────────────────────────────────────────┐  │
│  │ HPC/RFC    →   RFC          →   Multi-model                         │  │
│  │ forecasts      Subsystem        Ensembles out                       │  │
│  │                                 to Day 5                            │  │
│  │ SREF, others → ? ┄┄┄┄┄┄┄┄┄┄ →                                       │  │
│  └────────────────────────────────────────────────────────────────────┘  │
│  ┌────────────────────────────────────────────────────────────────────┐  │
│  │ GFS        →   GFS          →   Multi-model        →  Blender  →    │  │
│  │ forecasts      Subsystem        Ensembles out                      │  │   Blended
│  │                                 to Day 14                          │  │   ensembles
│  │ Others     → ? ┄┄┄┄┄┄┄┄┄┄ →                                        │  │   out to a year
│  └────────────────────────────────────────────────────────────────────┘  │
│  ┌────────────────────────────────────────────────────────────────────┐  │
│  │ CFS        →   CFS          →   Multi-model                        │  │
│  │ forecast       Subsystem        Ensembles out                      │  │
│  │                                 to a year                          │  │
│  │ Others     → ? ┄┄┄┄┄┄┄┄┄┄ →                                        │  │
│  └────────────────────────────────────────────────────────────────────┘  │
└──────────────────────────────────────────────────────────────────────────┘
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Envisioned Ensemble Pre-Processing for ~ Day 5

```
┌─────────────────────────────────────────────────────────────────────────────┐
│                                                                               │
│  ┌──────────────┐    ┌──────────────┐    ┌──────────────┐                     │
│  │ HPC/RFC single-│──▶│  Statistical │──▶│   Ensemble   │─┐                    │
│  │ value forecast │    │  processing  │    │              │  \                  │
│  └──────────────┘    └──────────────┘    └──────────────┘   \                 │
│                                                               \                │
│  ┌──────────────┐                          ┌──────────────┐    \               │
│  │ Other sing-value│────────────────────▶│ Single-value │─────┐               │
│  │   forecasts    │                          │  forecasts   │      \            │
│  └──────────────┘                          └──────────────┘       \           │
│                                                                      ▶┌──────────────┐   ┌──────────────┐
│  ┌──────────────┐    ┌──────────────┐    ┌──────────────┐          ▶│  Weighting   │──▶│ Multi-model  │
│  │Other single-value│──▶│ Statistical- │──▶│   Ensemble   │───────┘  │  (e.g. BMA)  │   │   ensemble   │
│  │   forecasts    │    │  processing  │    │              │          └──────────────┘   └──────────────┘
│  └──────────────┘    │ (e.g. analog)│    └──────────────┘         /
│                        └──────────────┘                            /
│  ┌──────────────┐    ┌──────────────┐    ┌──────────────┐        /
│  │  short-range   │──▶│ Statistical- │──▶│   Ensemble   │───────┘
│  │   ensemble     │    │  processing  │    │              │
│  │   forecasts    │    └──────────────┘    └──────────────┘
│  └──────────────┘                                                             │
│                                                                               │
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```

Envisioned Ensemble Pre-Processing for ~ Day 14

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┌─────────────────────────────────────────────────────────────────────────────────┐
│                                                                                     │
│  ┌──────────────┐     ┌──────────────┐     ┌──────────────┐                        │
│  │ GFS single-  │ ──▶ │ Statistical  │ ──▶ │  Ensemble    │                        │
│  │value forecast│     │ processing   │     │              │                        │
│  └──────────────┘     └──────────────┘     └──────────────┘                        │
│                                                                                     │
│  ┌──────────────┐                           ┌──────────────┐   ┌──────────────┐   ┌──────────────┐ │
│  │Other single- │ ───────────────────────▶  │ Single-value │   │  Weighting   │   │ Multi-model  │ │
│  │value forecasts│                          │  forecasts   │──▶│ (e.g. BMA)   │──▶│  ensemble    │ │
│  └──────────────┘                           └──────────────┘   └──────────────┘   └──────────────┘ │
│                                                                                     │
│  ┌──────────────┐     ┌──────────────┐     ┌──────────────┐                        │
│  │ GFS ensemble │ ──▶ │ Statistical  │ ──▶ │  Ensemble    │                        │
│  │  forecast    │     │ processing   │     │              │                        │
│  └──────────────┘     └──────────────┘     └──────────────┘                        │
│                                                                                     │
└─────────────────────────────────────────────────────────────────────────────────┘
```

Envisioned Ensemble Pre-Processing for ~ 1 Year

```
CPC monthly &          Adjustment of
seasonal          →    historical        →    Ensemble
outlook forecast       ensembles
                                                            ↘
                                                              Weighting        Multi-model
CFS forecast      →    Statistical       →    Ensemble    → (e.g. BMA)    →   ensemble
                       processing
                                                            ↗
                       Selection of
ENSO, PDO,        →    historical        →    Ensemble
AMO, etc.              ensembles
```

Adding Seasonal Prediction Component to NLDAS
(U. Washington)   (NWS Office of Hydrology)   (Princeton U.)
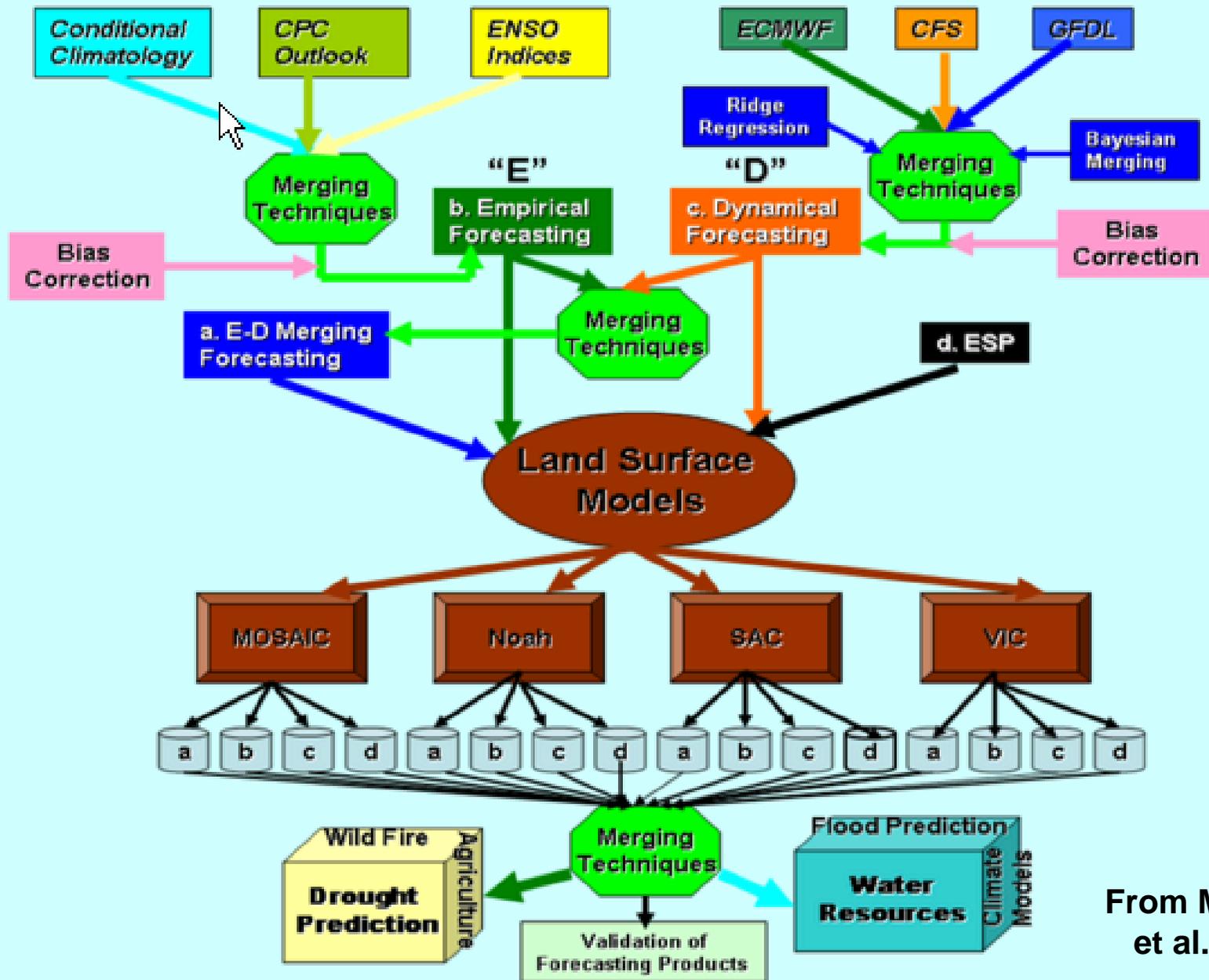
From Mitchell et al. 2006

NOAA Climate-Water
Research-to-Operations Program

Climate Testbed

NCPO Research Projects

CPPA Ensemble Project

CPPA Core Project

Advanced Hydrologic Prediction Service (AHPS)

Water Customers

Hydro-Testbed / Hydroclimatic Component
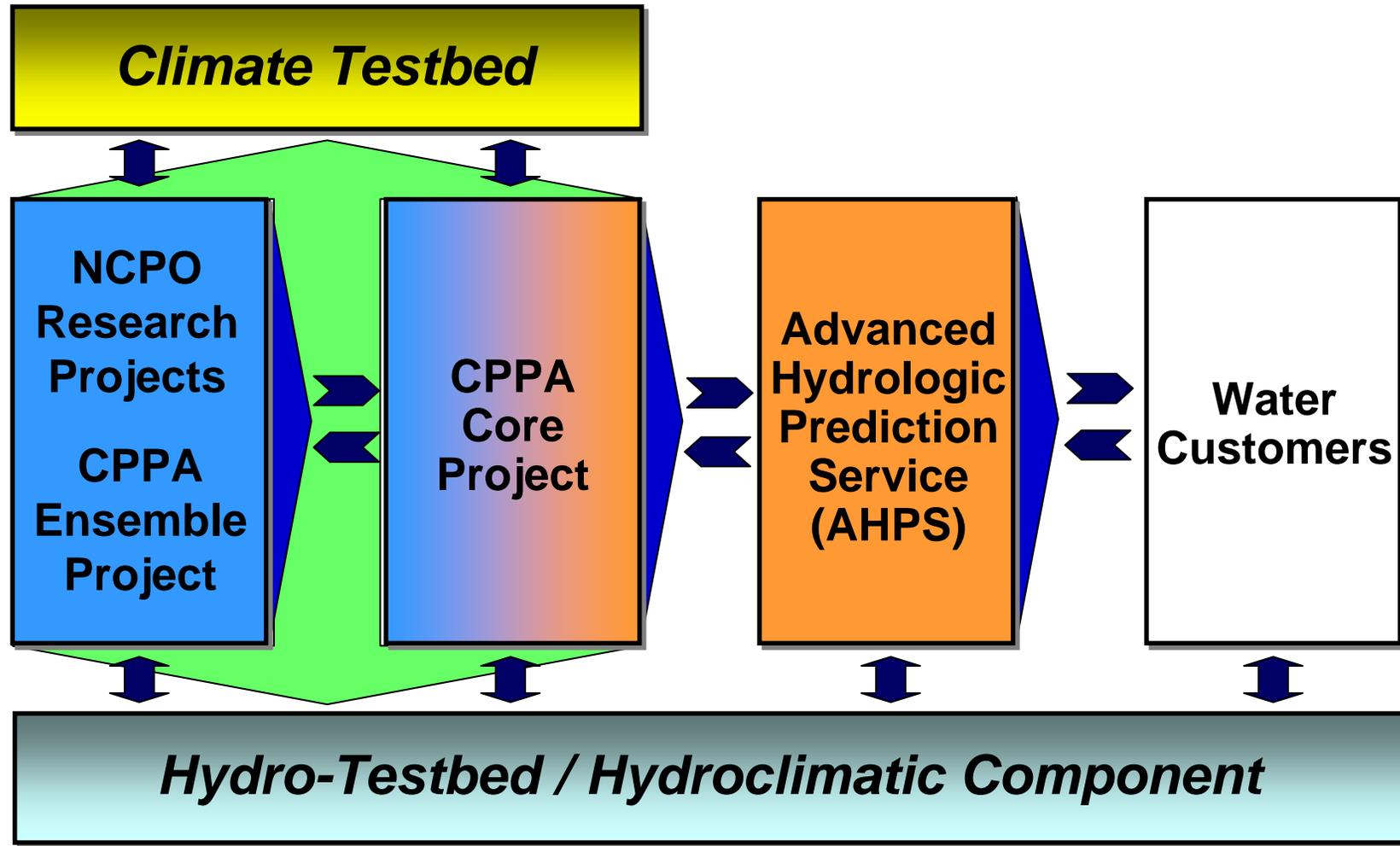
Collaboration with NCPO PIs

- NCEP (Mitchell, Toth et al.)
- Clark (Verification, ensemble prediction, data assimilation and pre-processor)
- East-Wide and West-Wide forecast system and Multi-model applications (Wood, Lettenmeier)
- K & A Georgakakos (INFORM, California)
- Alternative algorithms (Clark/Hay, Werner, Princeton, NCEP, others)
- Conditional uncertainty confidence (NCEP, Princeton, Washington)
- Verification statistics (Bradley, UCI, Arizona, Weber)
- Future unified NWS EPP

Data Assimilator

- **Balanced and phased approach**
  - Recognize that it may take some time to flush out the operations concept
    - How DA may best serve the forecasters
    - How DA may best complement/combine with forecaster MOD, Adjust-Q, statistical post-processing, etc.
  - Develop and infuse methodologies and techniques that support deterministic prediction with extensibility to ensemble prediction (e.g. VAR)
  - Further-develop and infuse methodologies and techniques for ensemble prediction (e.g. Maximum Likelihood Ensemble Filter)
- **Leverage NCPO/CPPA, NASA-funded activities**

VAR-aided forecast as time-lagged ensembles
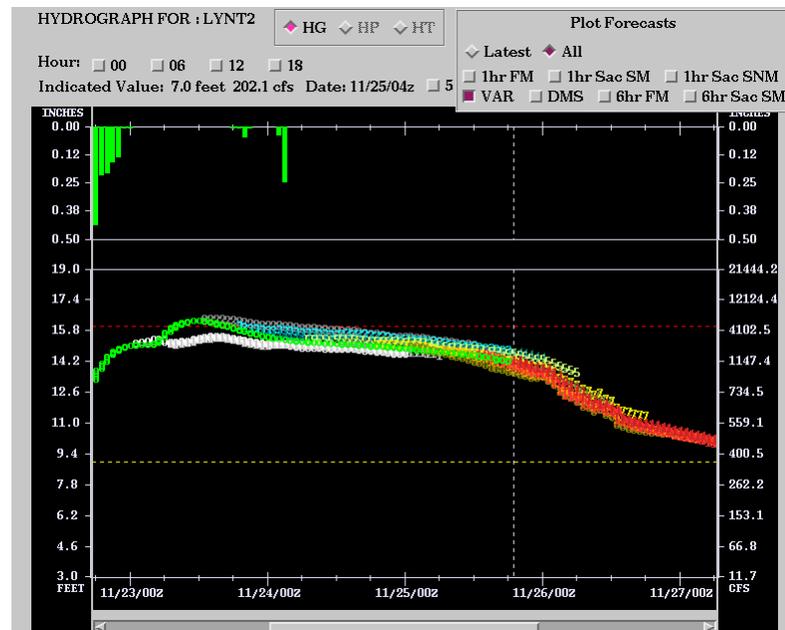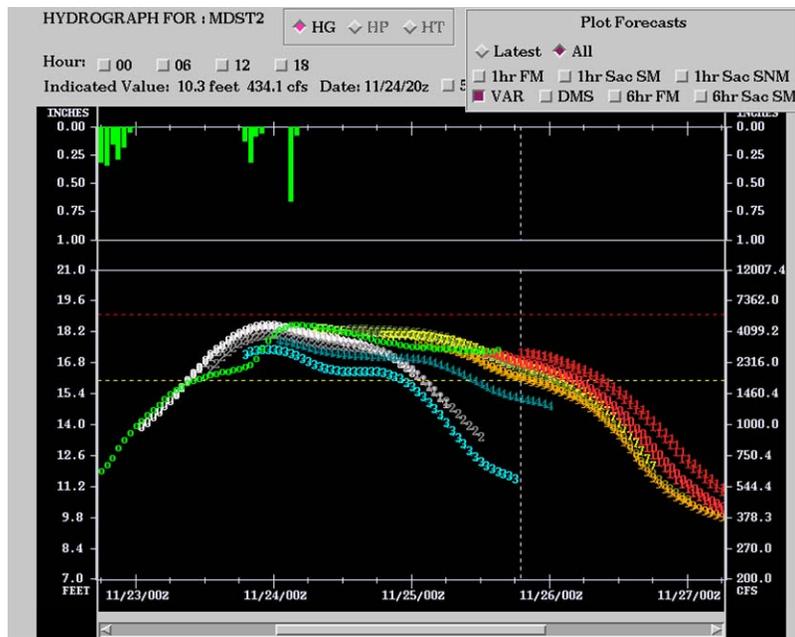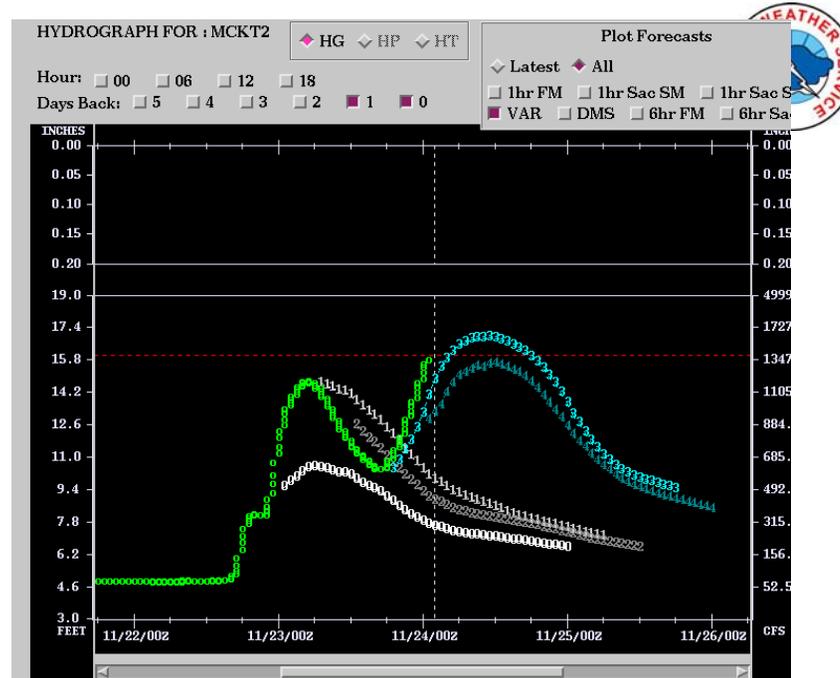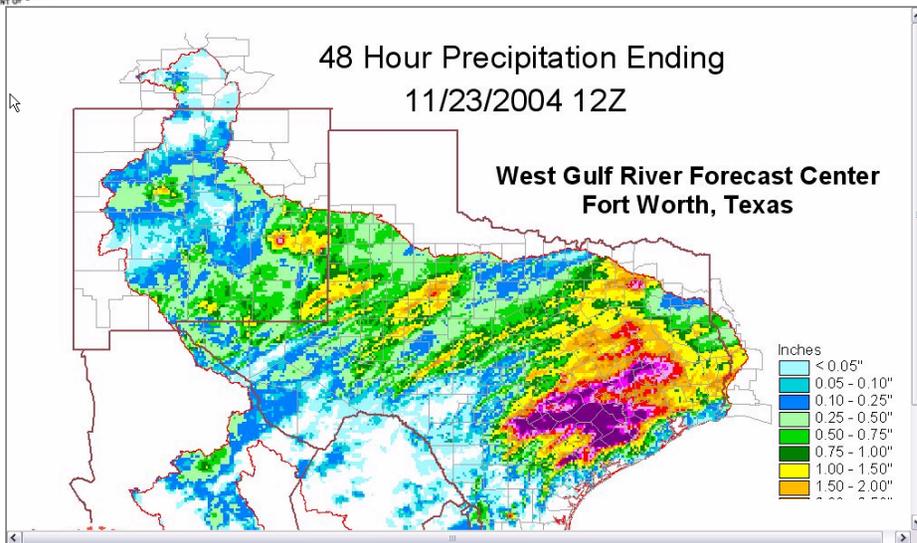
VAR-aided forecast as time-lagged ensembles (cont.)

11/03/2004 12Z

West Gulf River Forecast Center
Fort Worth, Texas
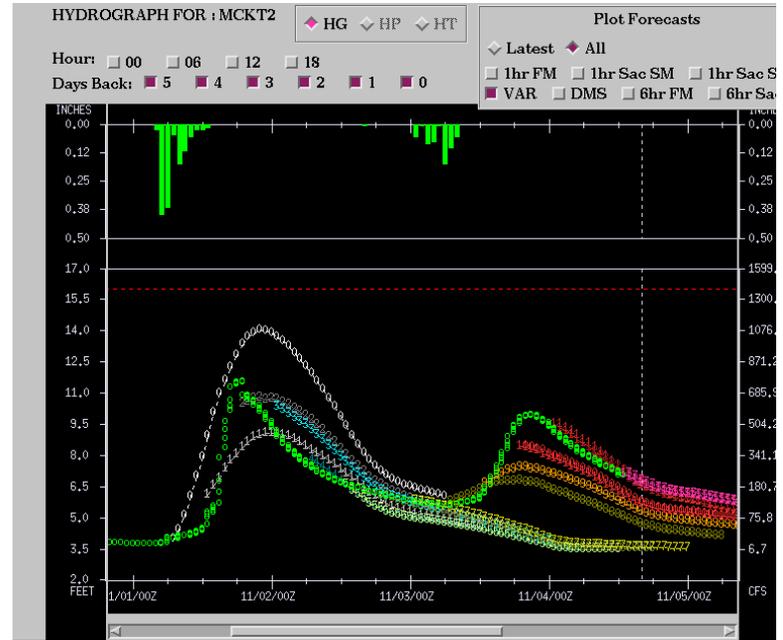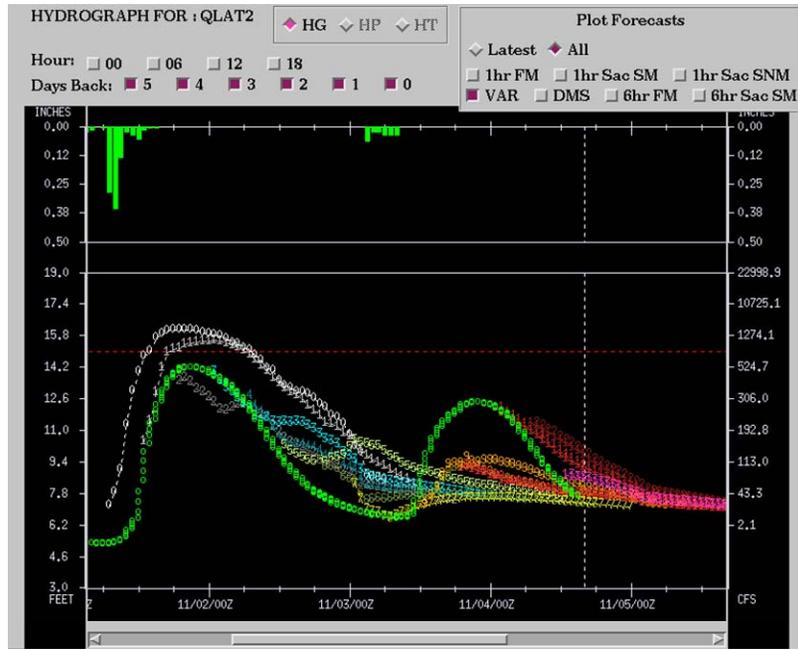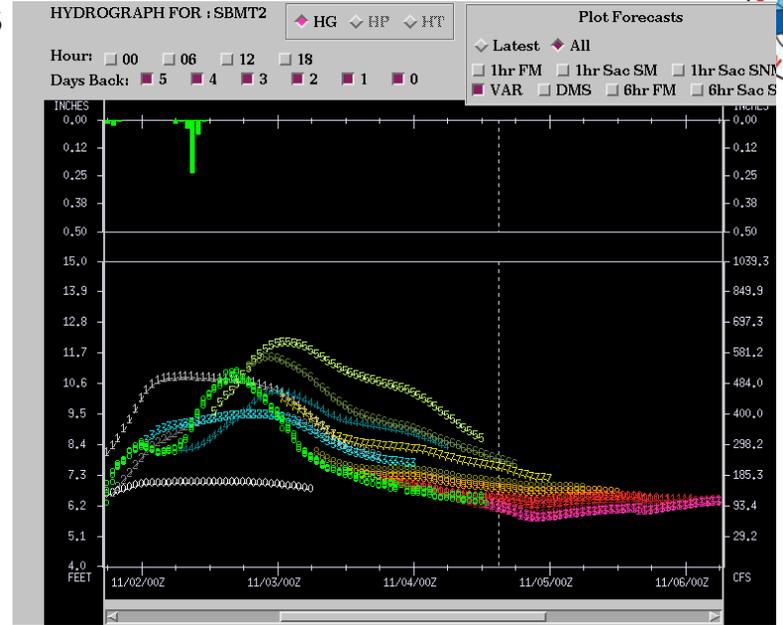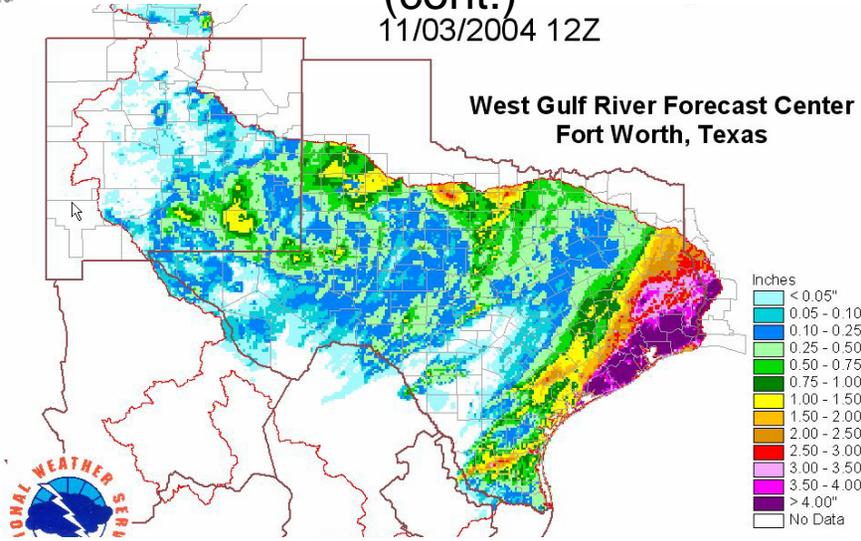
ILLUSTRATION OF DATA ASSIMILATION WITH DISTRIBUTED MODEL

ABRFC / WTTO2

WTTO2 Channel Network
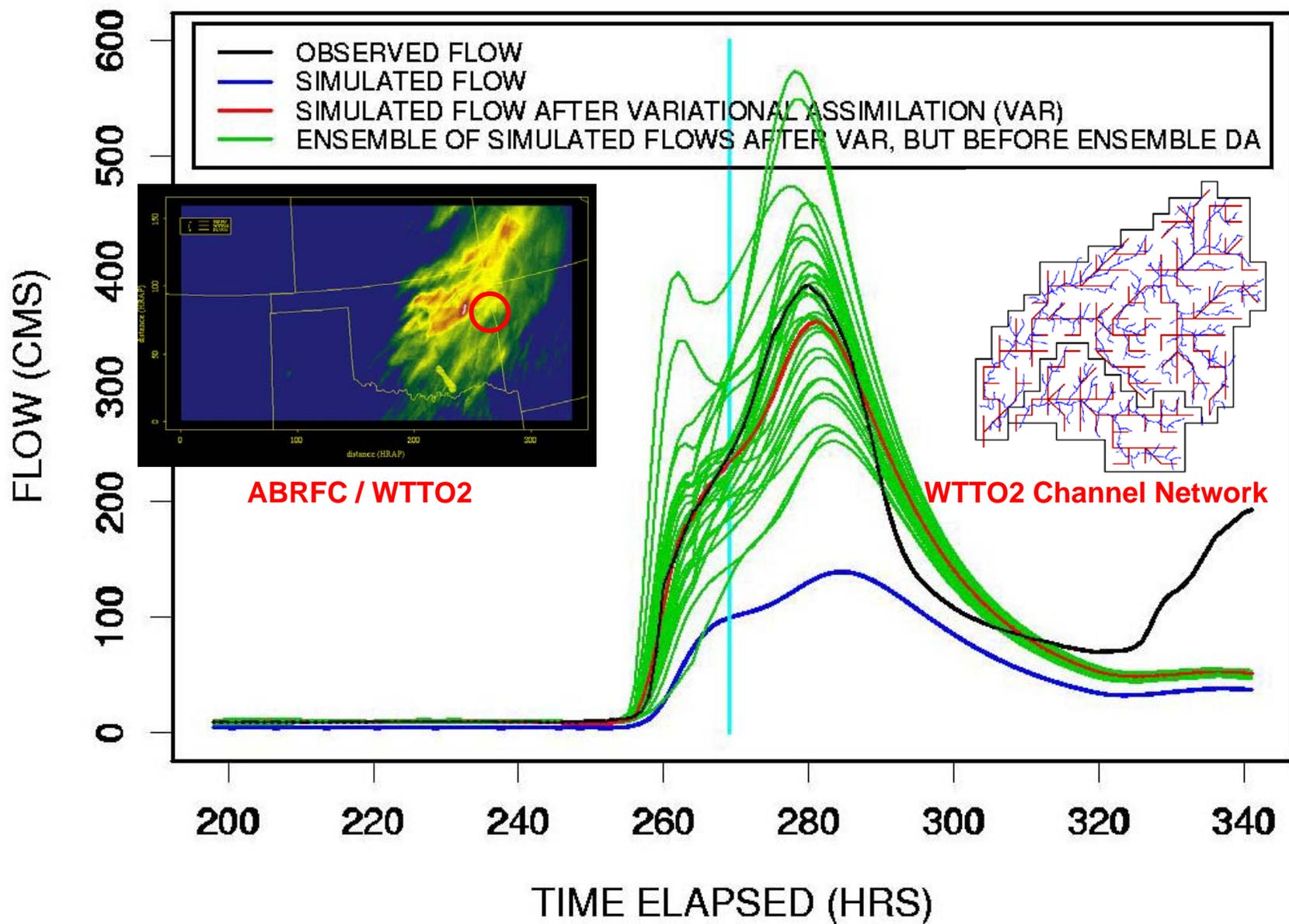
Data Assimilator - Strategy

CPPA external (Clark et al.)

MODIS-derived snow cover

AMSR-derived SWE[1]

Atmospheric forcing

In-situ snow water equivalent (SWE)

Snow models

SNODAS SWE

Snowmelt

MODIS-derived surface temperature

Potential evap. (PE)

Precipitation

MODIS-derived cloud cover

Soil moisture accounting models

In-situ soil moisture (SM)

AMSR-derived SM[1]

NASA-NWS (Restrepo (PI) Peters-Lidard (Co-PI) and Limaye (Co-PI) et al.)

Runoff

Hydrologic routing models

Streamflow or stage

Flow

CPPA Core, AHPS, Water Resources (Seo et al.)

Satellite altimetry

Hydraulic routing models

River flow or stage

Flow

[1] **pending assessment**

reservoir, etc., models

Ensemble Post-Processor

- Critically important to deal with hydrologic uncertainty, particularly in the absence of DA
  - Model structural uncertainty
  - Model parametric uncertainty
  - Initial condition uncertainty
- Couple with Adjust-Q
- Disaggregate daily to 6-hourly flows
- Operate at sub-daily time steps (6hrly, hourly)
- Assess requirements for data and ensemble size
- Explore accounting of uncertainty due to reservoir/flow regulation
  - Consider statistical approaches to reservoir modeling
- Improve the existing technique (Seo et al. 2006)
- Explore other techniques

Parametric Uncertainty Processor

- ## Longer-term activity
  - Computationally intensive
  - Need to improve understanding

- ## Leverage:
  - In-house and collaborative activities for hydrologic model calibration, parameter estimation, and uncertainty assessment and quantification
    - Model Parameter Estimation Experiment (MOPEX)
    - Distributed Model Intercomparison Project (DMIP)
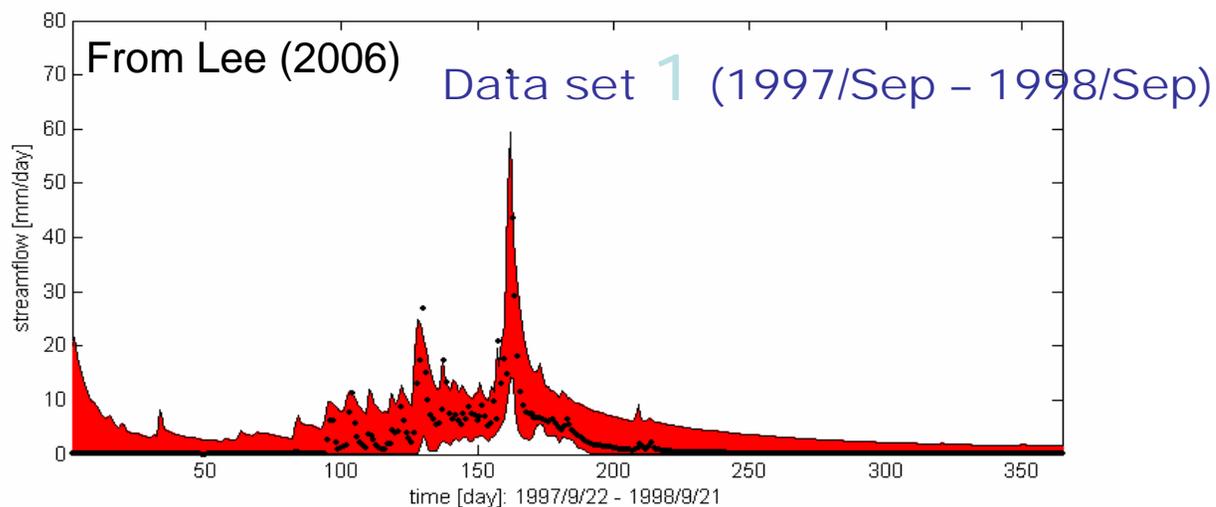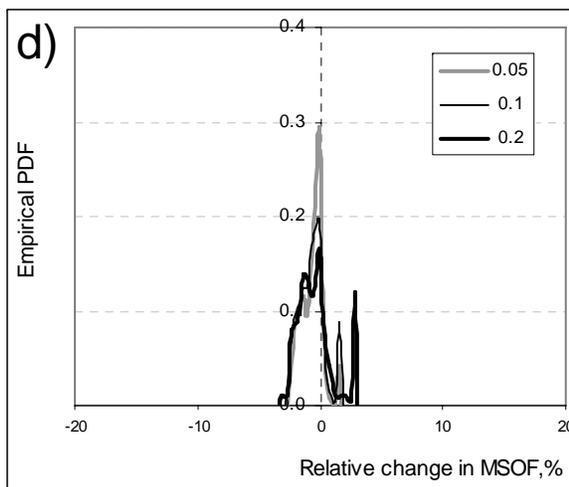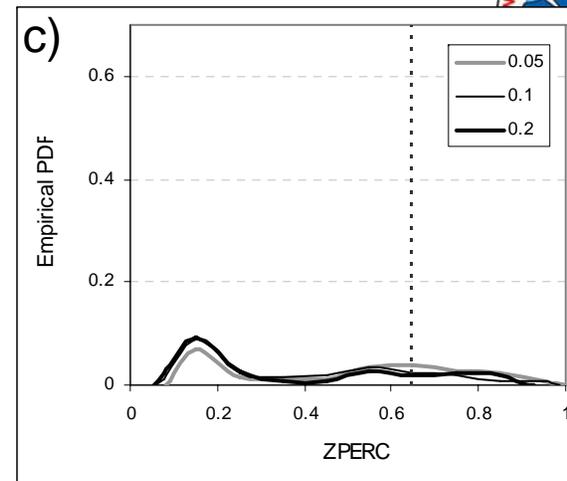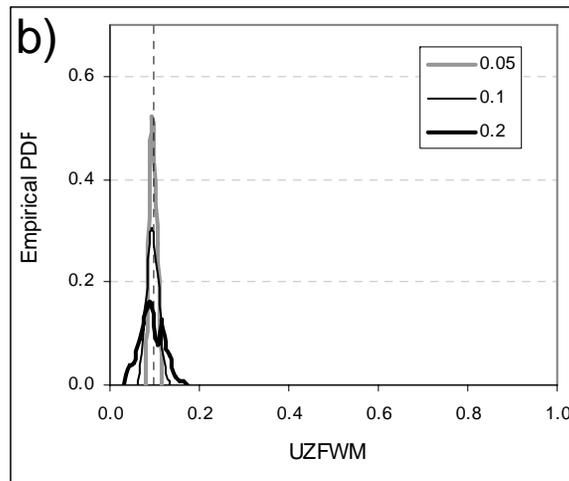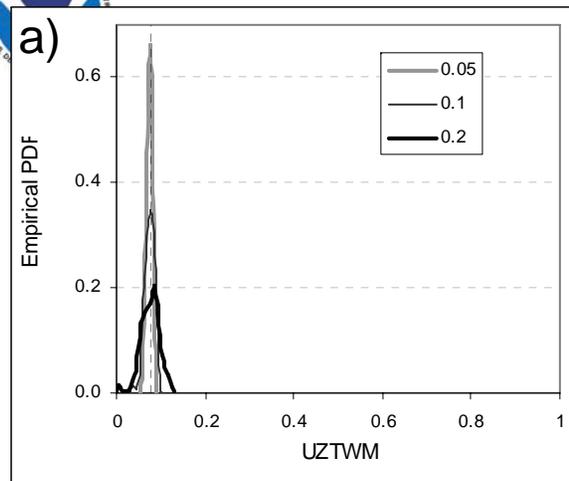
a) Empirical probability density functions of the posterior (i.e. optimized) estimate of UZTWM for ATIT2. The optimization is by SLS. The a priori value of UZTWM was given a random noise ranging from 5, 10 to 20 percent (denoted as 0.05, 0.1 and 0.2, respectively) of the spatial variability of the a priori UZTWM in the basin. b) Same as a), but for UZFWM. c) Same as a), but for ZPERC. d) Empirical probability density functions of the relative difference (From Kuzmin et al. 2006)

Anticipated FY07 AHPS Ensemble Projects

- Support experimental operation and AWIPS implementation of short-term ensemble applications

- Test, validate and comparatively verify the EPP2 GFS Subsystem

- Improve the Ensemble Pre-Processor II (EPP2)

- Evaluate the prototype Ensemble Post-Processor

- Enhance Data Assimilation capabilities for lumped SAC-UH

Anticipated FY07 AHPS Ensemble Projects (cont.)

- Ensemble Verification: add metrics from the Verification Plan (and Confidence Intervals) and enhance display capabilities in the Ensemble Verification System (EVS); release and support experimental EVS

- Ensemble Verification: develop error analysis, enhance ensemble hindcaster, release and support experimental hindcaster

- Ensemble Verification: evaluate existing archiving capabilities

How to better-organize and strengthen OHD-RFC collaborative R&D and RTO activities and fast-track STE capabilities to RFC operations?
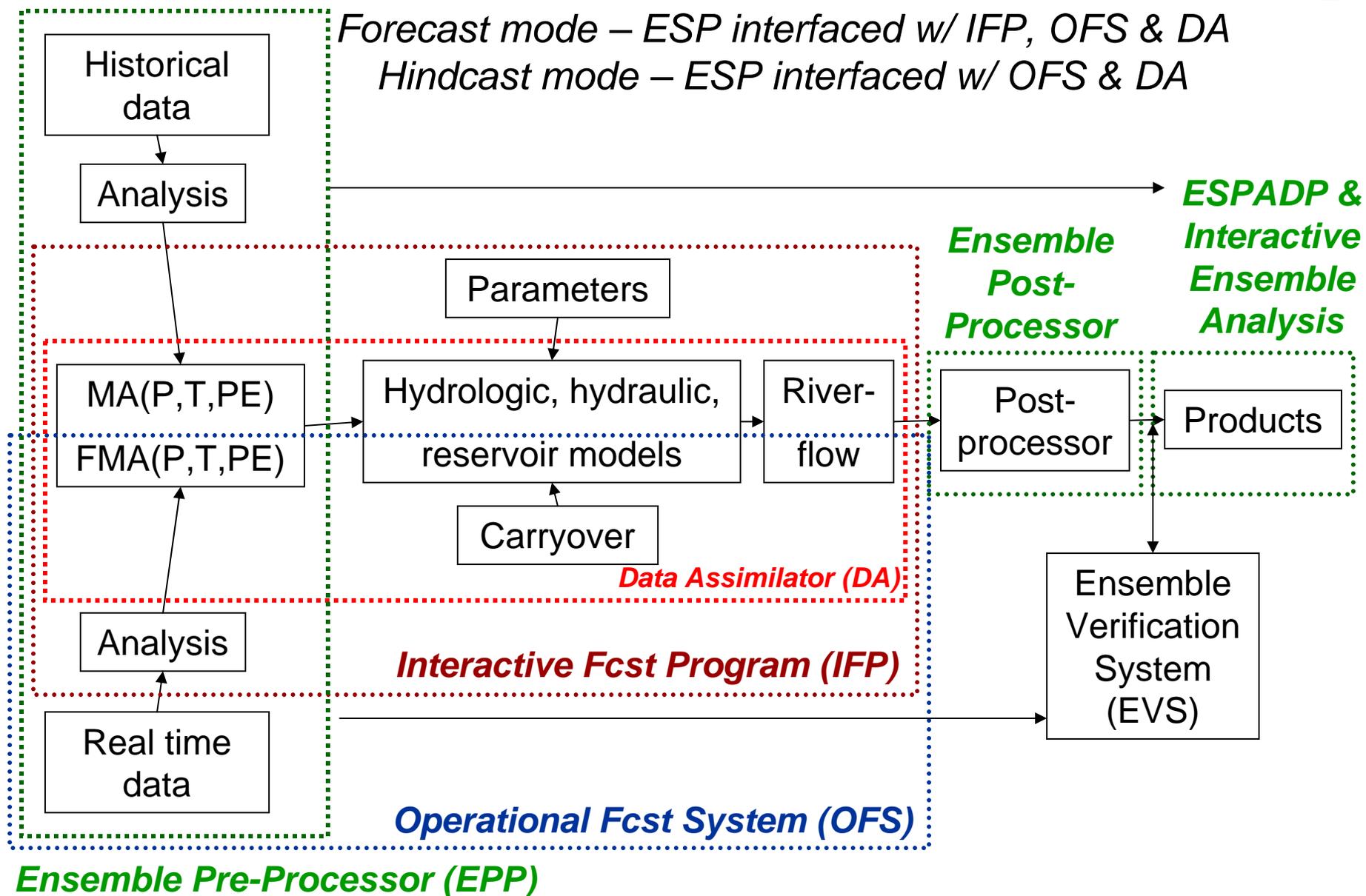
Experimental Ensemble Forecast System (XEFS)

Rob Hartman, CNRFC

D.-J. Seo, OHD

NOAA/National Weather Service

Targeted Baseline Ensemble forecast system

Forecast mode – ESP interfaced w/ IFP, OFS & DA
Hindcast mode – ESP interfaced w/ OFS & DA

Ensemble Post-Processor

ESPADP & Interactive Ensemble Analysis

Historical data

Analysis

Parameters

MA(P,T,PE)
FMA(P,T,PE)

Hydrologic, hydraulic, reservoir models

River-flow

Post-processor

Products

Carryover

Data Assimilator (DA)

Interactive Fcst Program (IFP)

Analysis

Real time data

Ensemble Verification System (EVS)

Operational Fcst System (OFS)

Ensemble Pre-Processor (EPP)

Elements of a Hydrologic Ensemble Prediction System

```
┌─────────────────┐        ┌─────────────────┐
│  QPE, QTE,       │        │    QPF, QTF      │
│  Soil Moisture   │        │                  │
└─────────────────┘        └─────────────────┘
         │                           │
         │                           ▼
         │                  ┌─────────────────┐
         │                  │ Ensemble Pre-    │
         │                  │ Processor        │
         │                  └─────────────────┘
         │                           │
         ▼                           ▼
┌──────────────────────────────────────────────────────────────────────┐
│  ┌──────────┐        ┌──────────────────┐        ┌──────────────────┐ │
│  │  Data    │───────▶│ Hydrology & Water │◀───────│  Parametric      │ │
│  │ Assimilator│      │ Resources Models  │        │  Uncertainty     │ │
│  └──────────┘        └──────────────────┘        │  Processor       │ │
│       ▲                        │                  └──────────────────┘ │
└───────┼────────────────────────┼──────────────────────────────────────┘
        │                        ▼
 ┌──────────────┐       ┌──────────────────┐    Hydrologic Ensemble
 │  Streamflow  │──────▶│ Ensemble Post-    │    Processor
 └──────────────┘       │ Processor         │
                        └──────────────────┘
                                 │
                                 ▼
                 ┌──────────────────────────────────┐
                 │ Hydrology & Water Resources       │
                 │ Ensemble Product Generator        │
                 └──────────────────────────────────┘
```

Objectives

- Develop a baseline prototype system that will serve the RFCs as an interim ensemble forecasting capability

- Develop an ensemble forecasting infrastructure common to OHD and RFCs that will help us:
  - Develop requirements and operations concept
  - Identify areas of science enhancements
  - Assess value and performance of additional capabilities and features

- Expedite maturation of the system components that can be readily transitioned to operations in AWIPS/FEWS
  - Service Oriented Architecture in 3-10 years (projected)

Components of Baseline System

- **Primary Components**
  - Ensemble Pre-Processor
  - Hydrologic Ensemble Processor
    - w/o Data Assimilator or Parametric Uncertainty Processor in the baseline but w/ extensibility
  - Ensemble Post-Processor
  - Product Generator and Analysis Tool
  - To operate in both real-time and hindcast modes
- **Support Components**
  - System Diagnostic Tool
  - Ensemble Verification System

Baseline Ensemble Pre-Processor

- **Existing capabilities**
  - EPP2 RFC Subsystem, GFS Subsystem
- **Needs**
  - An integrated Ensemble Pre-Processor, EPP3
- **Gap**
  - Science enhancements (conditional bias, intermittency,PoP, etc.)
  - Access, ingest and pre-processing of CFS forecast
  - Generation of CPC outlook-based long-term ensembles
  - Blending of short- and long-term ensembles
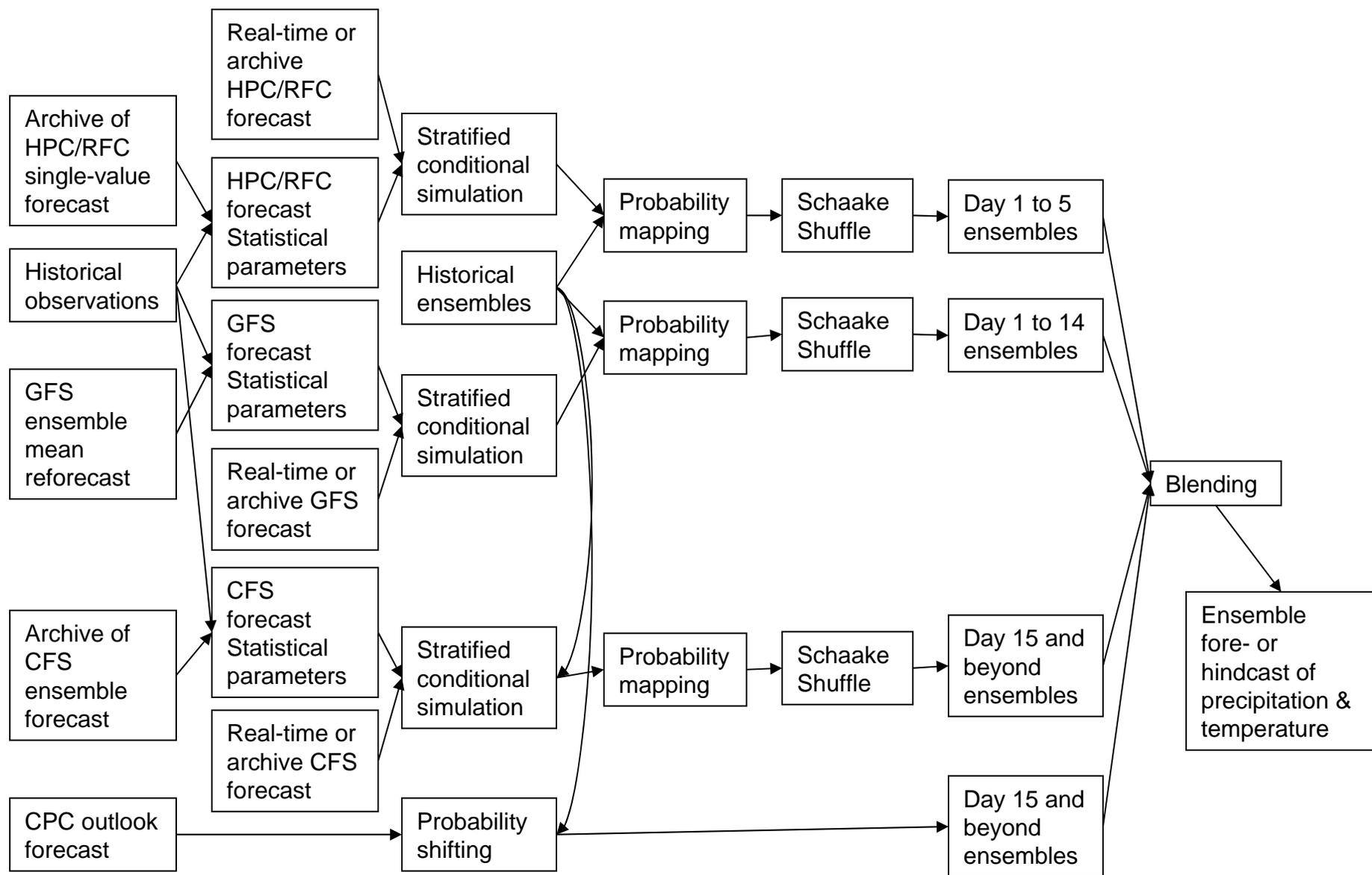- **Additional capabilities to be identified through the prototyping process**

EPP3 User Interface

- Existing capabilities
  - Scripts
- Needs
  - A prototype user interface
- Gap
  - A user interface to:
    - Configure the run
    - Execute the run
    - Review the results
    - Visualize
      - Run status, precipitation and temperature ensembles, single-value forecasts, ensemble mean, climatology, etc.
      - With zoom/pan capability to examine short- and long-term ensembles
    - Display capability to serve both pre- and post-processed ensembles
    - Additional capabilities to be identified through the prototyping process
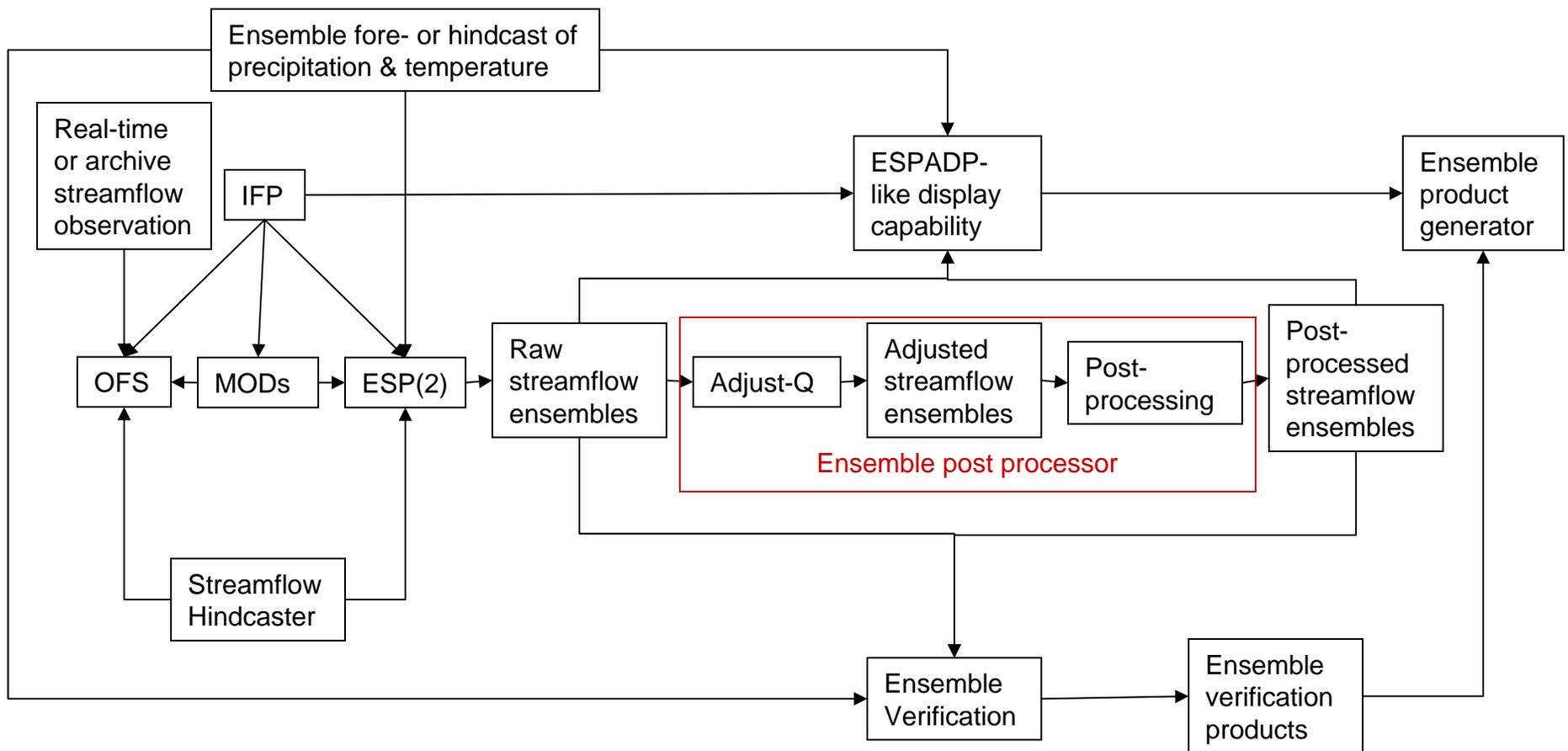   - Conceptual functional specifications under development

Workflow for Baseline EPP (EPP3)

Real-time or archive HPC/RFC forecast

Archive of HPC/RFC single-value forecast

Historical observations

GFS ensemble mean reforecast

Archive of CFS ensemble forecast

CPC outlook forecast

HPC/RFC forecast Statistical parameters

GFS forecast Statistical parameters

Real-time or archive GFS forecast

CFS forecast Statistical parameters

Real-time or archive CFS forecast

Stratified conditional simulation

Historical ensembles

Stratified conditional simulation

Stratified conditional simulation

Probability shifting

Probability mapping → Schaake Shuffle → Day 1 to 5 ensembles

Probability mapping → Schaake Shuffle → Day 1 to 14 ensembles

Probability mapping → Schaake Shuffle → Day 15 and beyond ensembles

Day 15 and beyond ensembles

Blending → Ensemble fore- or hindcast of precipitation & temperature

Workflow for Baseline Hydrologic Ensemble Processor & Ensemble Post-Processor

Baseline Hydrologic Ensemble Processor

- Existing capabilities
    - ESP
- Needs
    - Run ESP interactively and in parallel with the deterministic forecasting operations using OFS and IFP
- Gap
    - Launch ESP from the IFP specific to the segment of interest (through operations table)
    - ESP to utilize all or some MODs including Adjust-Q
    - ESP generates adjusted simulated results
    - ESP issues with carryover, locks, time shifts, etc.
    - Others, yet to be discovered
- Additional capabilities to be identified through the prototyping process

- Probably need an alternate version of ESP (ESP2)

Baseline Ensemble Post-Processor

- **Existing capabilities**
  - An AWIPS prototype
    - Bias and uncertainty correction of daily flow
- **Needs**
  - Enhancements and development of guidance for use with Adjust-Q, MOD
- **GAP**
  - Adjust Q capability (also needed in ESP)
  - Improved bias and uncertainty correction
  - Operation at sub-daily time steps (6hrly, hourly)
  - Disaggregation of daily to 6-hrly flows
  - Assessment of sample size requirement (number of ensemble members needed)

Baseline Ensemble Analysis User Interface

- Existing capabilities
  - ESPADP
- Needs
  - Segment specific interface w/ simple controls
  - Interactive version of ESPADP designed for serial operations (batch option)
- Gap
  - Initiated through IFP by OFS in the operations table
    - global technique to turn on/off
    - new operation
    - launches and executes segment specific ESP
    - specifies input/output/distribution/post-processing techniques, defaults, etc.
  - Displays ESPADP-type information and graphics with and without
    - post processing
    - single-value forecasts
    - climatology
  - Allows forecaster to over-ride default settings and re-generate ensembles
  - Allows forecaster modulation/selection/adjustment of post-processing and analysis techniques
  - Allows generation of prototype products

Baseline Ensemble Verification

- Existing capabilities
  - Prototype Ensemble Verification System (EVS)
- Needs
  - Additional functionalities
  - Improved user friendliness
- Gap
  - Verify stage
  - Develop easy-to-understand verification statistics for hydrology that can be easily and clearly communicated to the customers and users
  - Add other verification statistics (rank histogram, discrimination measures, continuous RPS, etc.)
  - Extend the lead time of the forecast and define additional time steps for long-term ESP verification
  - Enhance display capabilities
  - Compute confidence intervals for the verification statistics

Timelines

- Develop draft design of baseline experimental ensemble system and vet through team

- Identify gaps
  - develop functional specifications for gaps and establish resource requirements and priority of each

- Design and gap analysis to be completed in 2-3 months

- Specific activities that follow depend on design document

Discussion