Part I: the Office of Hydrologic Development Strategic Science Plan

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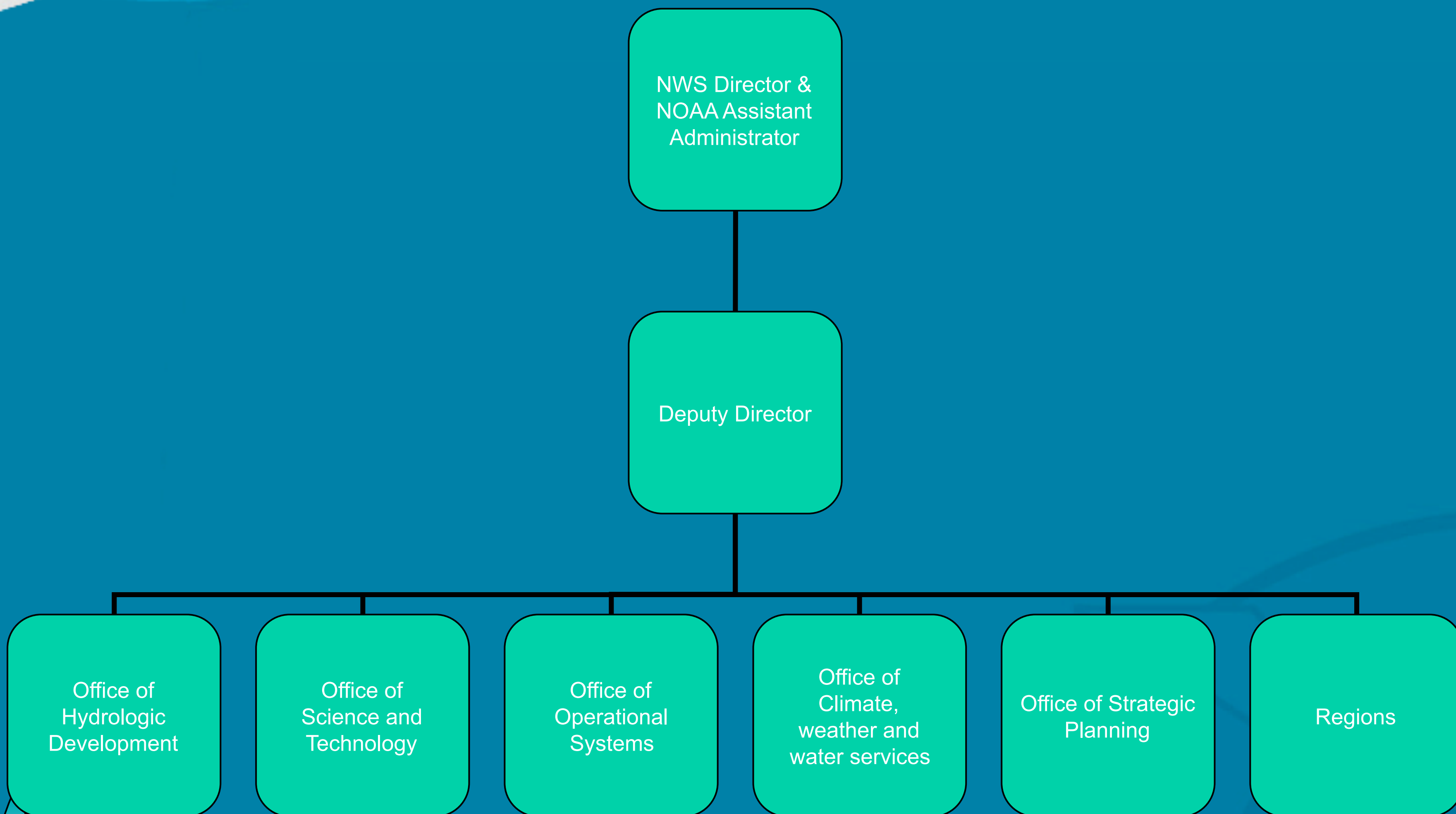
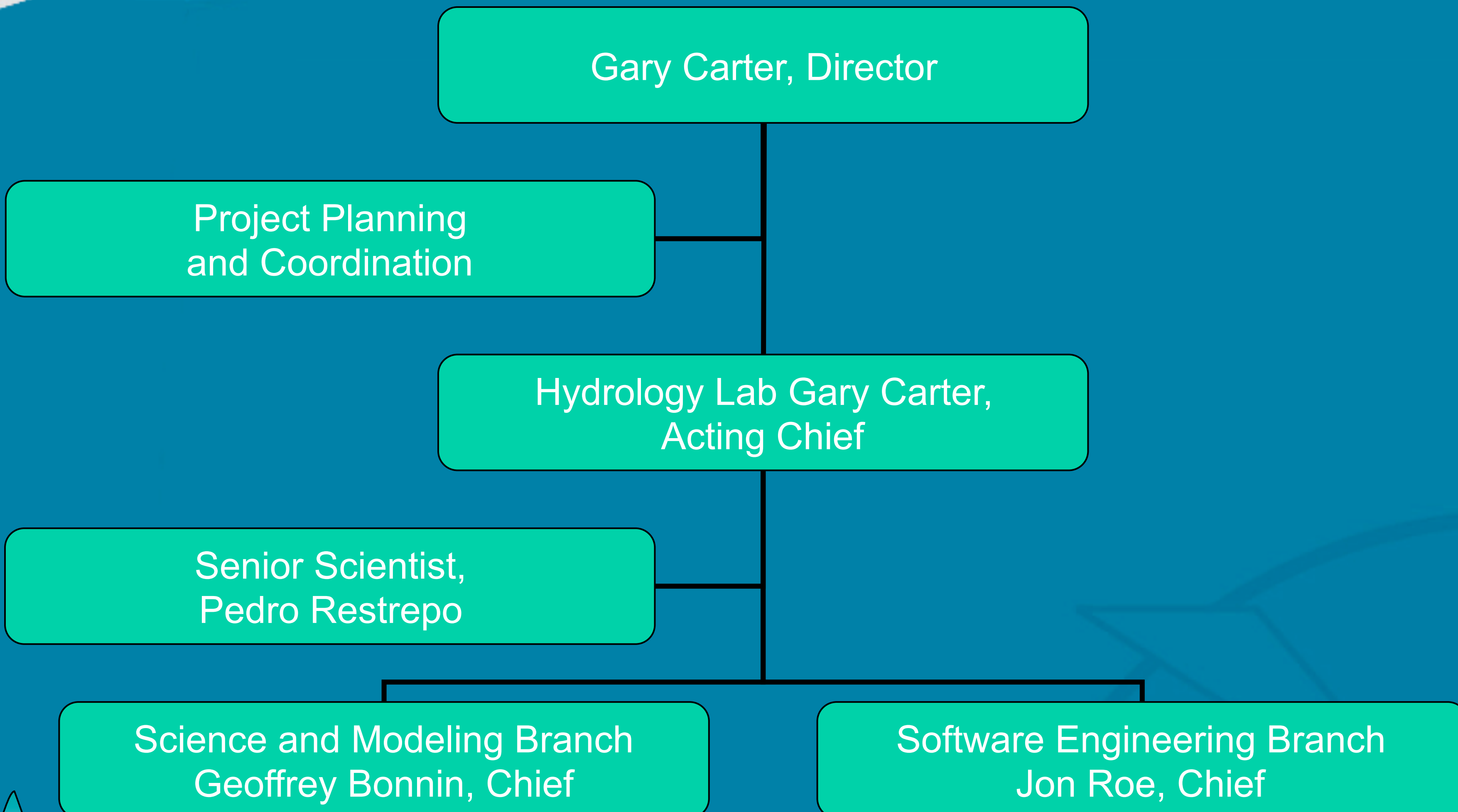
April, 2009

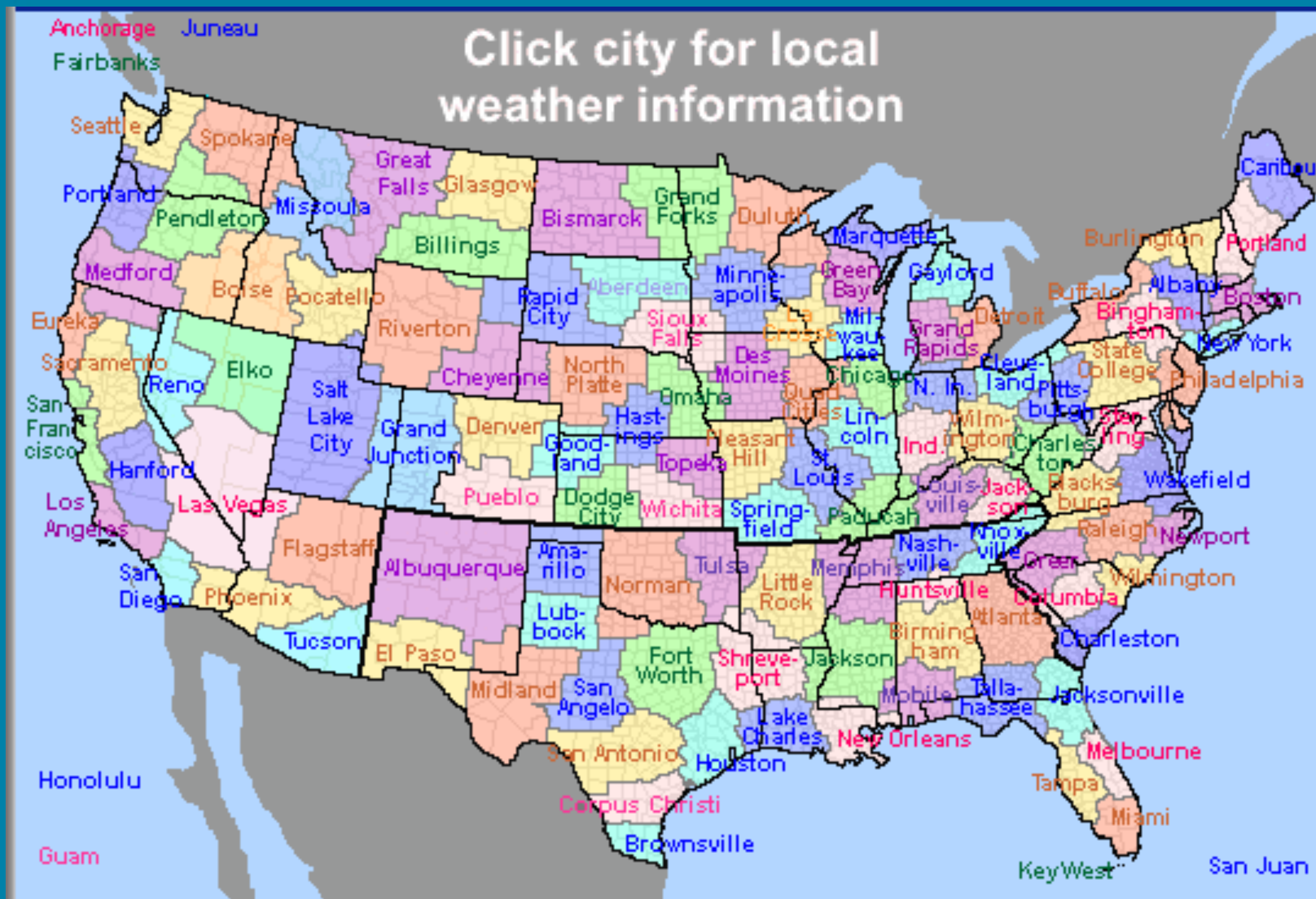
National Weather Service Headquarters Organization



Office of Hydrologic Development



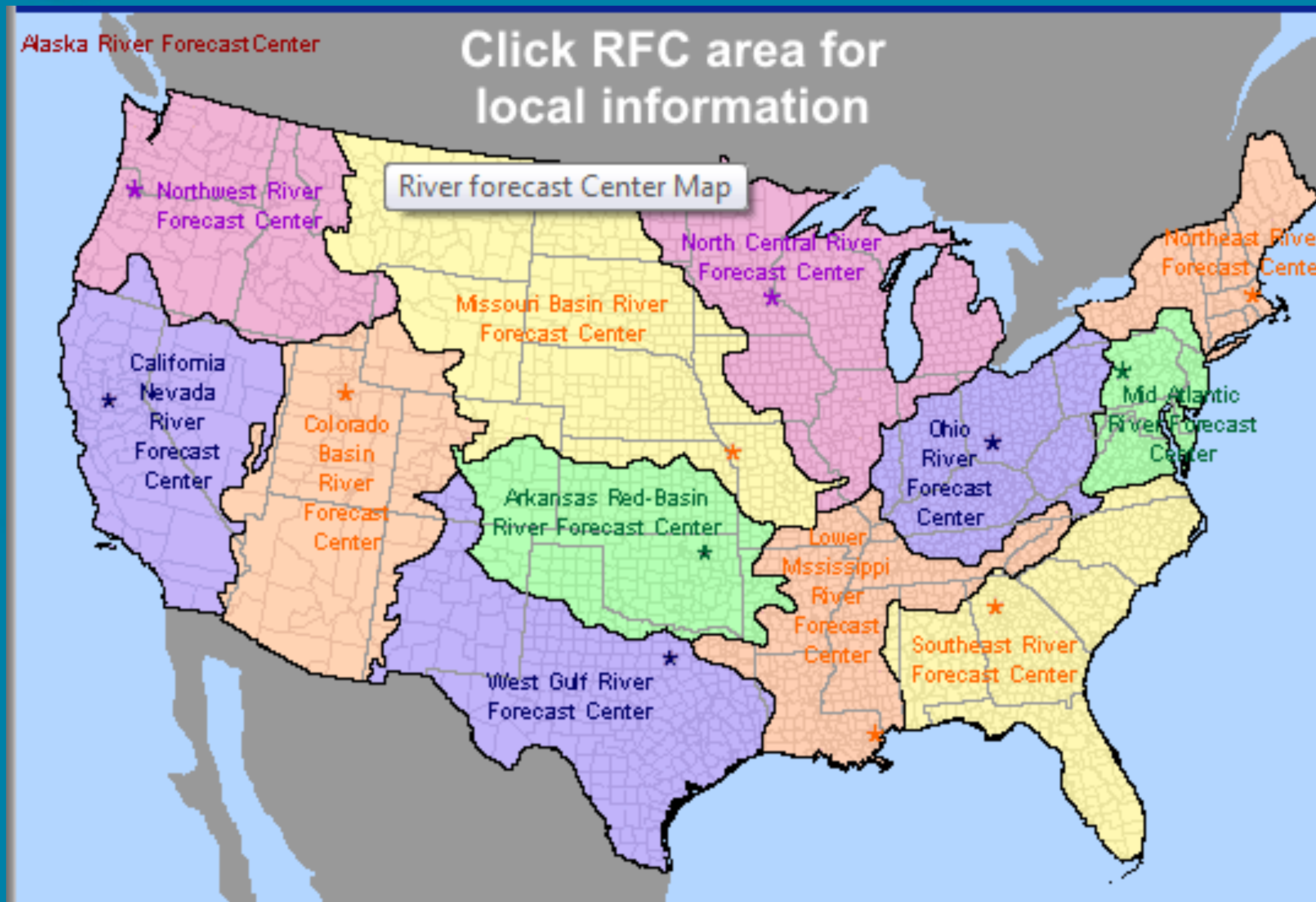
Weather Forecast Offices



Water Predictions for Life Decisions

National Weather Service

River Forecast Centers



Water Predictions for Life Decisions

Current Research at OHD

- Hydrology Group
- Hydrometeorology Group
- Ensemble, Data Assimilation and Verification Group
- Hydraulics Group

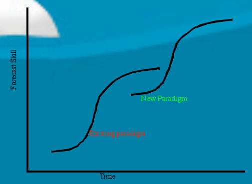
The Future of Hydrologic Forecasting at the NWS

- Enhanced use of remotely sensed information on a wide range of atmospheric and land-surface characteristics, from both active and passive satellite-based and/or airborne sensors;
- Higher-resolution models;
- Explicit consideration of the uncertainty in the forcings and forecasts (An ensemble approach is currently being pursued and will be fully implemented for short-, medium- and long-term forecasting);
- Multi-model ensembles to address the problem of uncertainty in the forecasts arising from structural errors in the models (These ensembles may be formed by combinations of lumped or distributed, conceptual or physically based models);
- Explicit consideration of the errors introduced by sub-optimal parameter values and initial conditions;
- Data assimilation of *in-situ* and remote-sensed state variables; and
- Verification of single-value (deterministic) and ensemble (probabilistic) forecasts.

The Future of Hydrologic Modeling

- Current Shortfalls of Physically Based Hydrologic Models
  - The models are typically based on small-scale hydrologic theory and thereby fail to account for larger-scale processes such as preferential flow paths;
  - The data necessary to estimate parameter values are not available at high enough resolution, certainty, or both;
  - The data necessary to drive the models are not available at high enough resolution, certainty or both; and
  - Despite the rapid increase in computer power and decrease in hardware costs, the computational demands are still a barrier, particularly for performing data assimilation and ensemble modeling in real-time.

How advances in predictability science transition to improved operational predictions

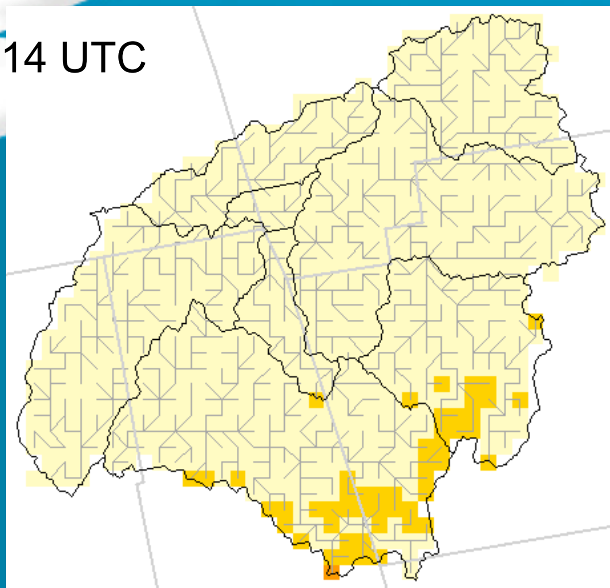


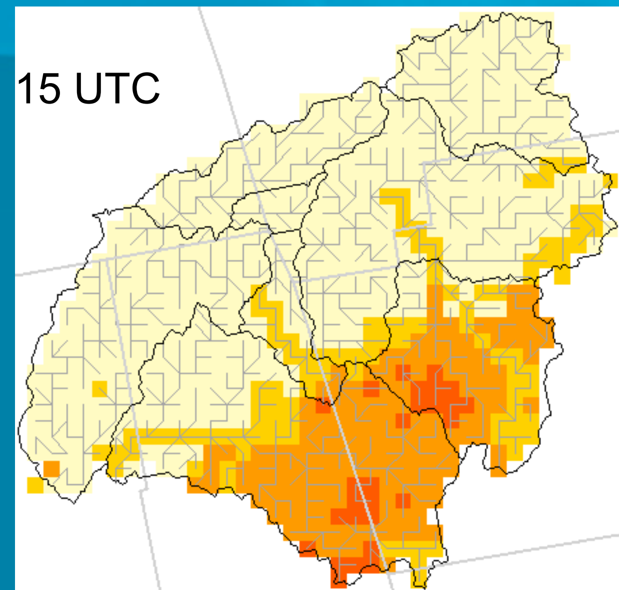
Adapted from: NRC 2002

Hydrologic Models

- Continued research and development on physically based models offers the potential for:
  - More accurate forecasts in ungauged and poorly gauged basins;
  - More accurate forecasts after changes in land use and land cover, such as forest fires and other large-scale disturbances to soil and vegetation;
  - More accurate forecasts under non-stationary climate conditions;
  - Modeling of interior states and fluxes, which are critical for forecasts of water quality, soil moisture, land slides, groundwater levels, low flows, etc.; and
  - The ability to merge hydrologic forecasting models with those for weather and climate forecasting.

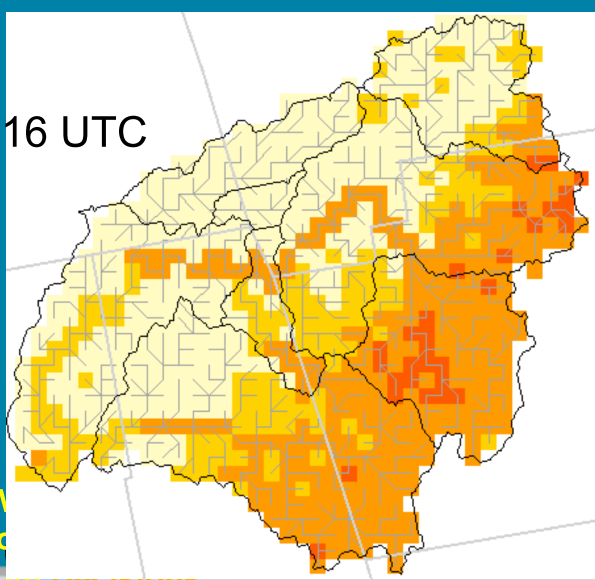
Hydrology Group

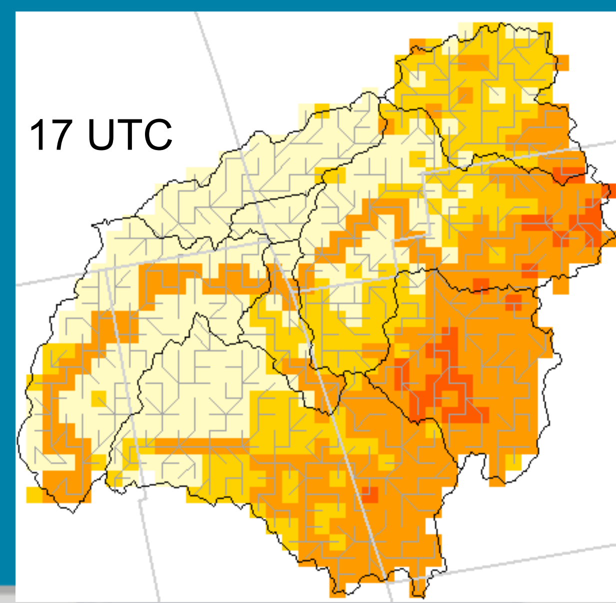




In these examples, frequencies are derived from routed flows, demonstrating the capability to forecast floods in locations downstream of where the rainfall occurred.

ARI (years)
1 - 2
2 - 3
3 - 5
5 - 10
10 - 20
No Data



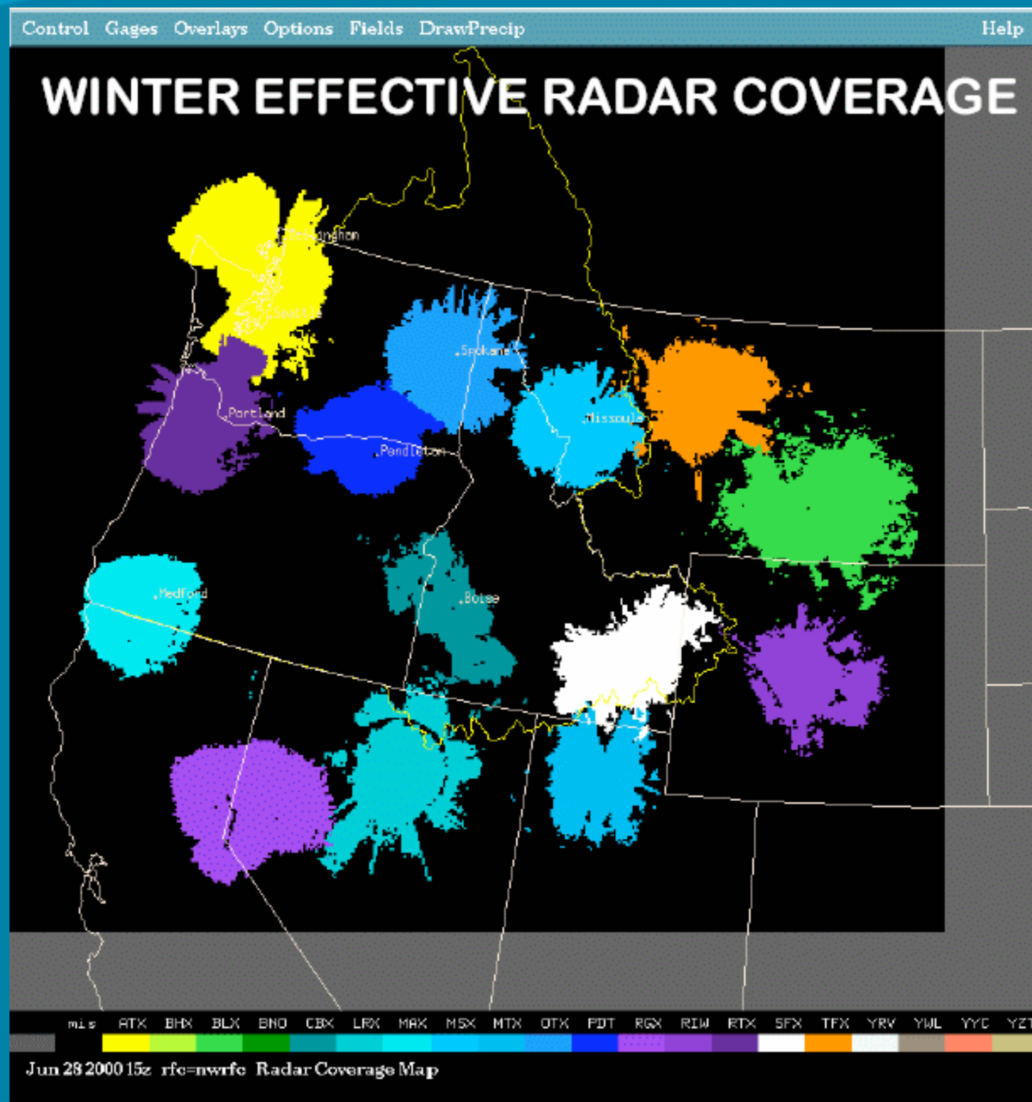


Flood frequencies are expressed in terms of the Average Recurrence Interval (ARI) associated with the annual maximum flood.

Precipitation Observations- Where we are

- Precipitation is the primary driver for streamflow, affecting discharge through surface runoff, subsurface flow, groundwater recharge, and snowmelt
- Varying time scale of the watershed response to precipitation input, depending on the watershed size and characteristics, from minutes to months.
- For areas well covered with radar and raingauges:
  - Multisensor Precipitation Estimator
  - USACE-developed P3 algorithm, enhanced and used at the ABRFC
  - Mountain mapper, developed at the CBRFC

Winter Effective Radar Coverage



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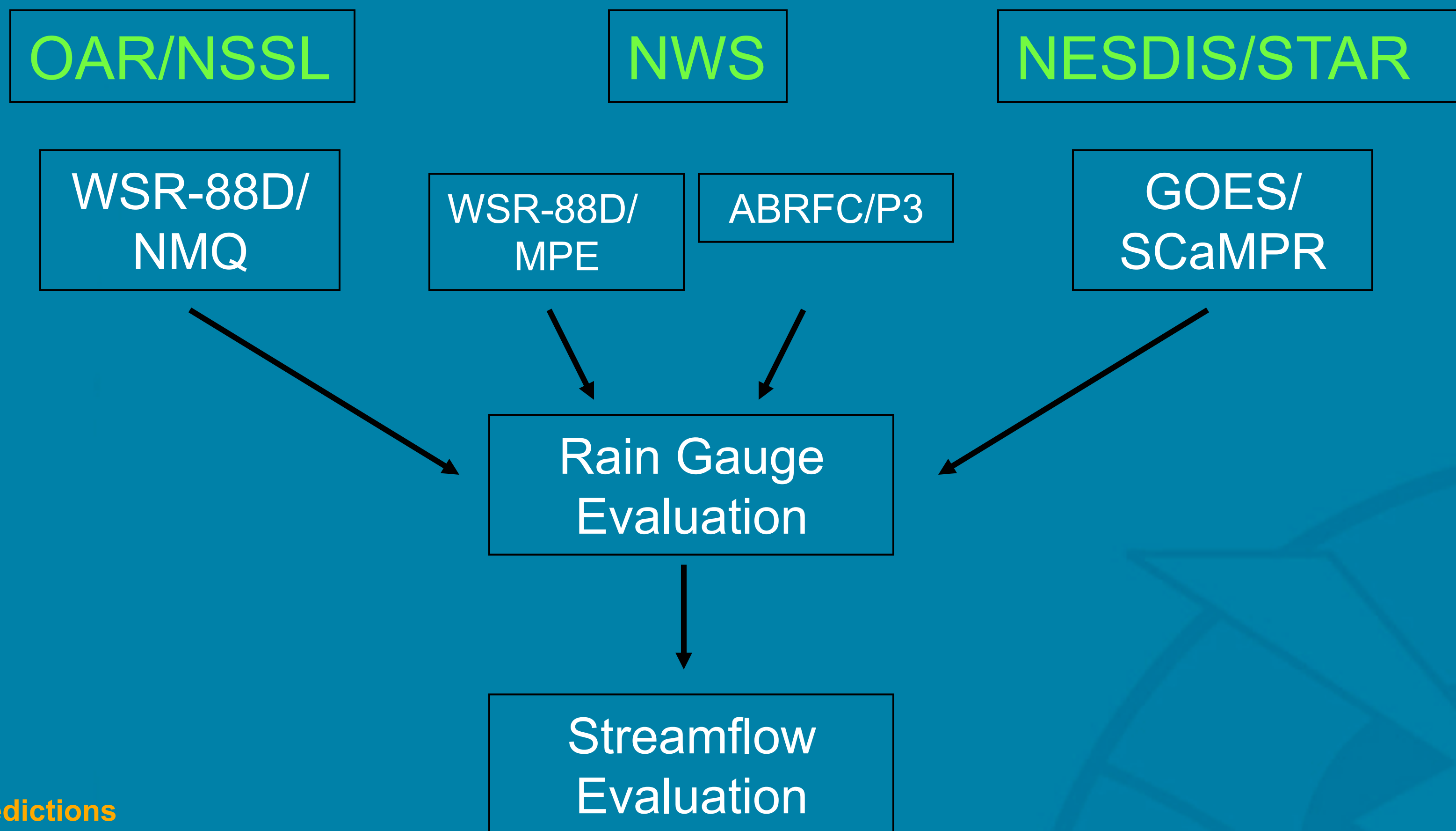
NOAA Precipitation Observation Algorithms



Precipitation Observations- Where we want to be

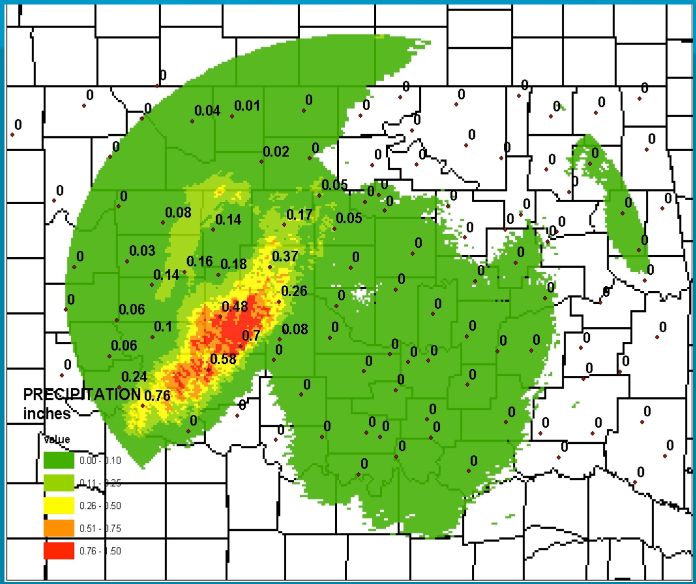
- Continuous, routine integration of all available sensor data and where needed, numerical prediction model estimates.
- Characterizations of the statistical distributions of estimation error will be used by the multisensor algorithms, and will be available to end users
- For radar:
  - implementation of dual-polarization algorithms
  - introduction of reflectivity profile and range corrections
  - automated selection of Z-R relationships
  - Spatial error understanding and modeling
  - Gap-filling radars in mountainous regions
- For satellite:
  - Implementation of algorithms for automatic real-time calibration of infrared temperature vs. rain-rate relationships based on collocated satellite and radar data
  - Anticipating the GPM deployment, OHD will explore applications of the Tropical Radar Rainfall Measurement Mission (TRMM) observations
  - Improved precipitation estimates by combining new satellite algorithms with numerical model prediction results (NOAA-CREST, Sayesteh Mahani)

Precipitation Forecasting- Where we are

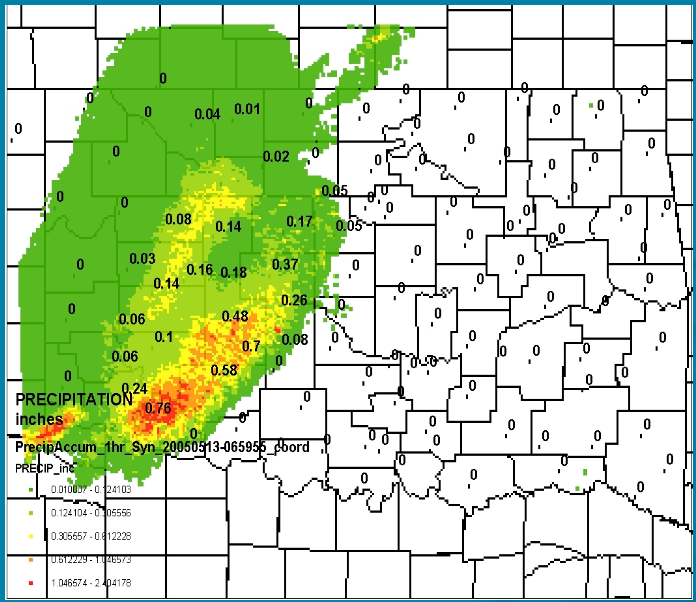
- Short-term nowcasting (< 3 hours)
- Near-term forecasting (3-12 hours) by a combination of radar-feature extrapolation and output from the Global Forecast System (GFS) and North American Mesoscale (NAM) models.
  - Manual modifications based on experience and physical logic are made to gridded precipitation fields by NCEP forecasters, and by HAS forecasters at RFCs. Output from the two models is subjectively weighted according to recent performance in the areas of interest.
  - Longer-term forecasts are based on GFS and NAM output

Hydrometeorology Group

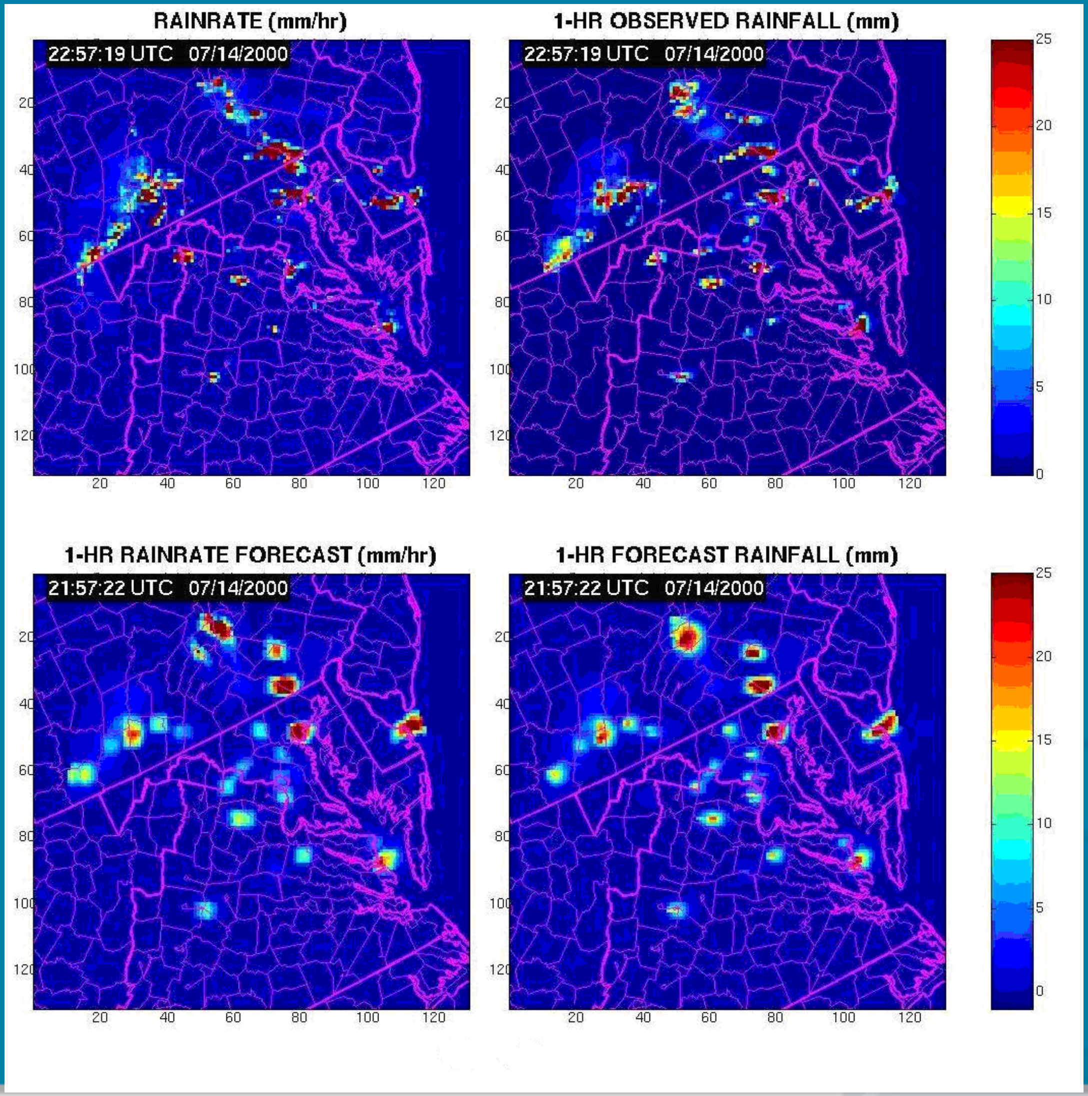
Current Radars (WSR88D)



New Radars (Dual Polarization)



High-resolution Precipitation Nowcaster

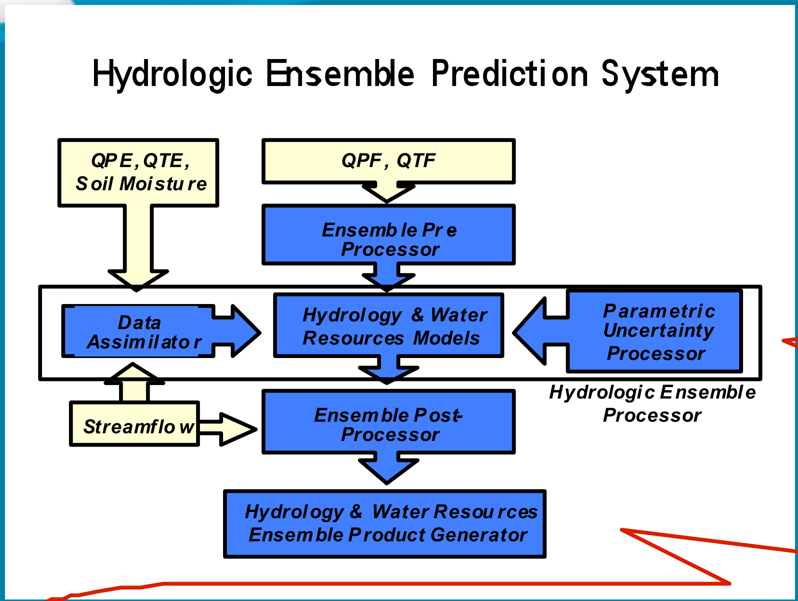


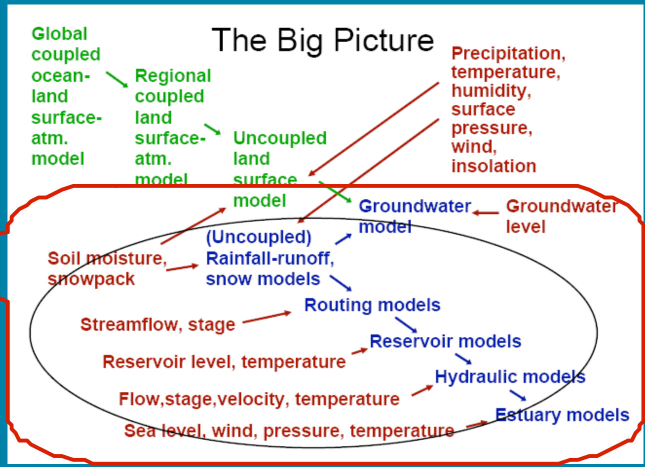
Water Predictions for Life Decisions

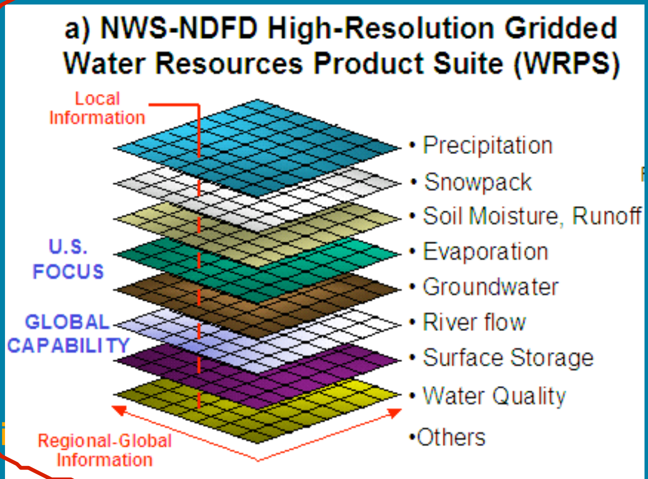
Ensemble Forecasting and Data Assimilation- Where we are

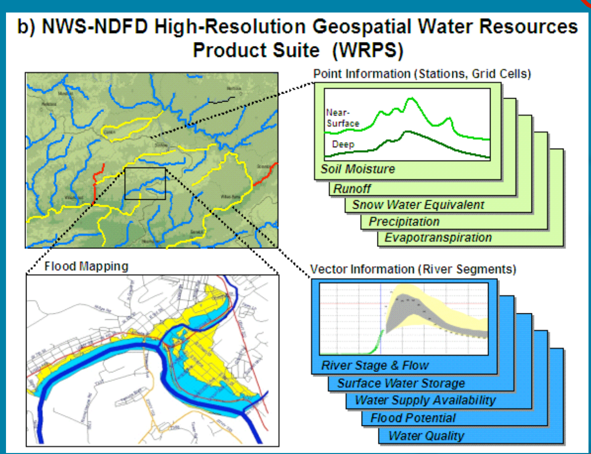
- Until now, operational ensemble forecast has been limited to Ensemble Streamflow Prediction (ESP) runs, essentially a long-range probabilistic forecast.
- Since AHPS, NWS is committed to generate streamflow forecasts at all time scales: customers and partners clearly indicate a need for short-term forecasts.
  - Ensemble pre-processor, to generate QPF and QTF short-term ensembles from single-value weather forecasts.
  - Ensemble post-processor to account for hydrologic uncertainty and river regulation
  - Hydrologic Ensemble Hindcaster, to support large-sample verification of streamflow ensembles
  - Ensemble Verification System for verification of precipitation, temperature and streamflow ensembles
- Partners: NCEP, HEPEX, Universities, RFCs, NASA Goddard, etc.

Ensembles- Where we want to be



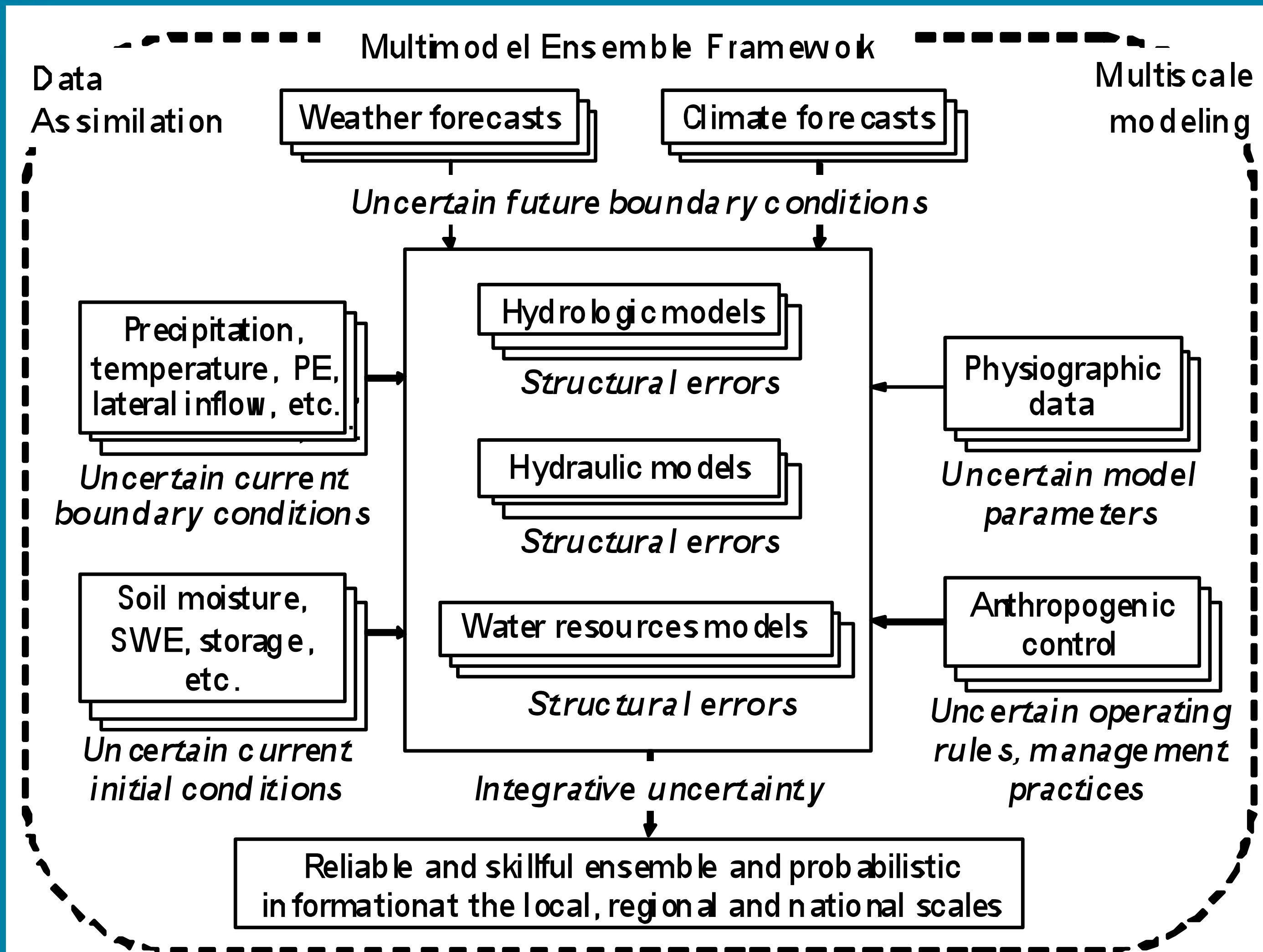






Improved accuracy, Reliable uncertainty estimates, Benefit-cost effectiveness maximized

Multimodel Ensemble Framework



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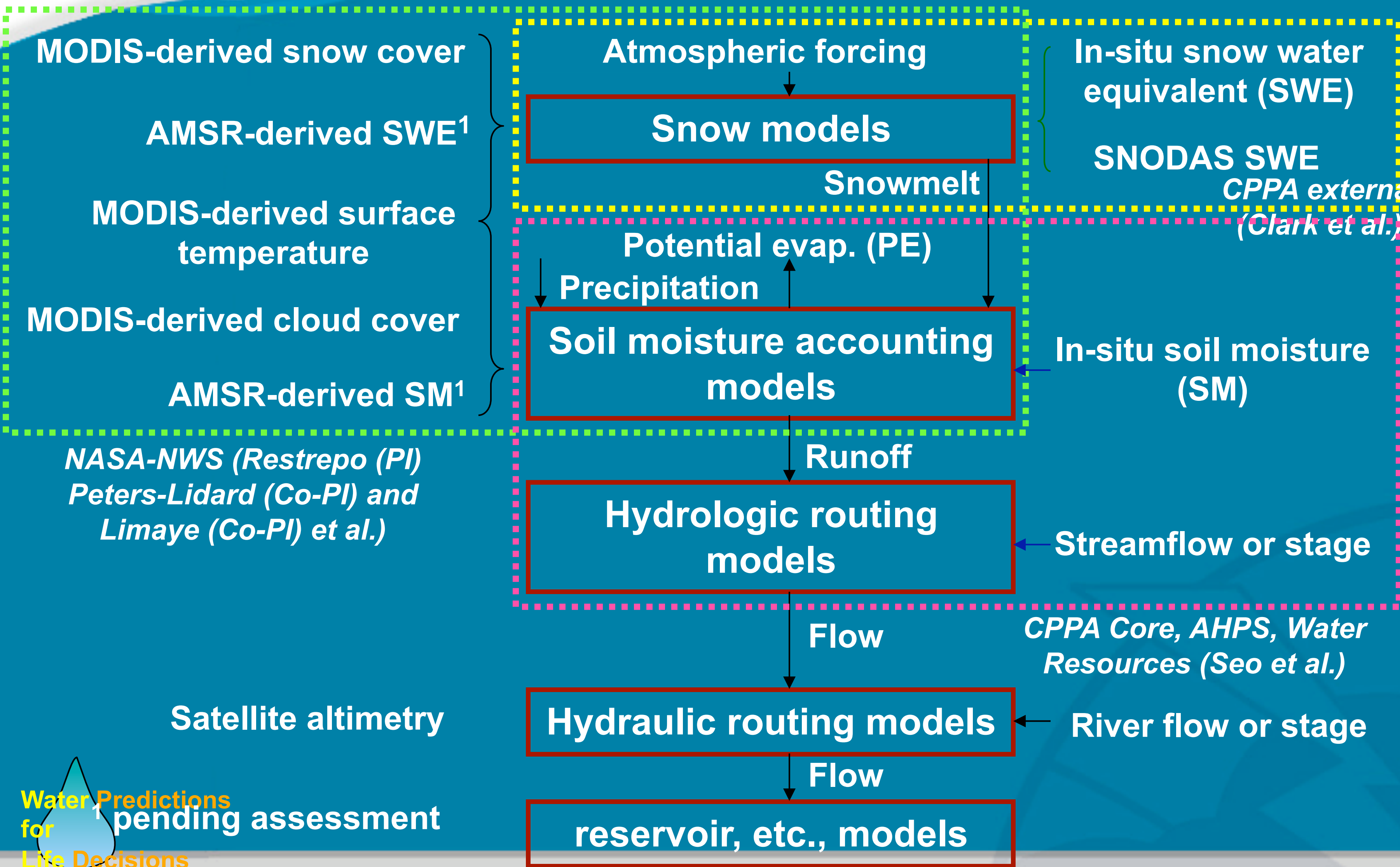
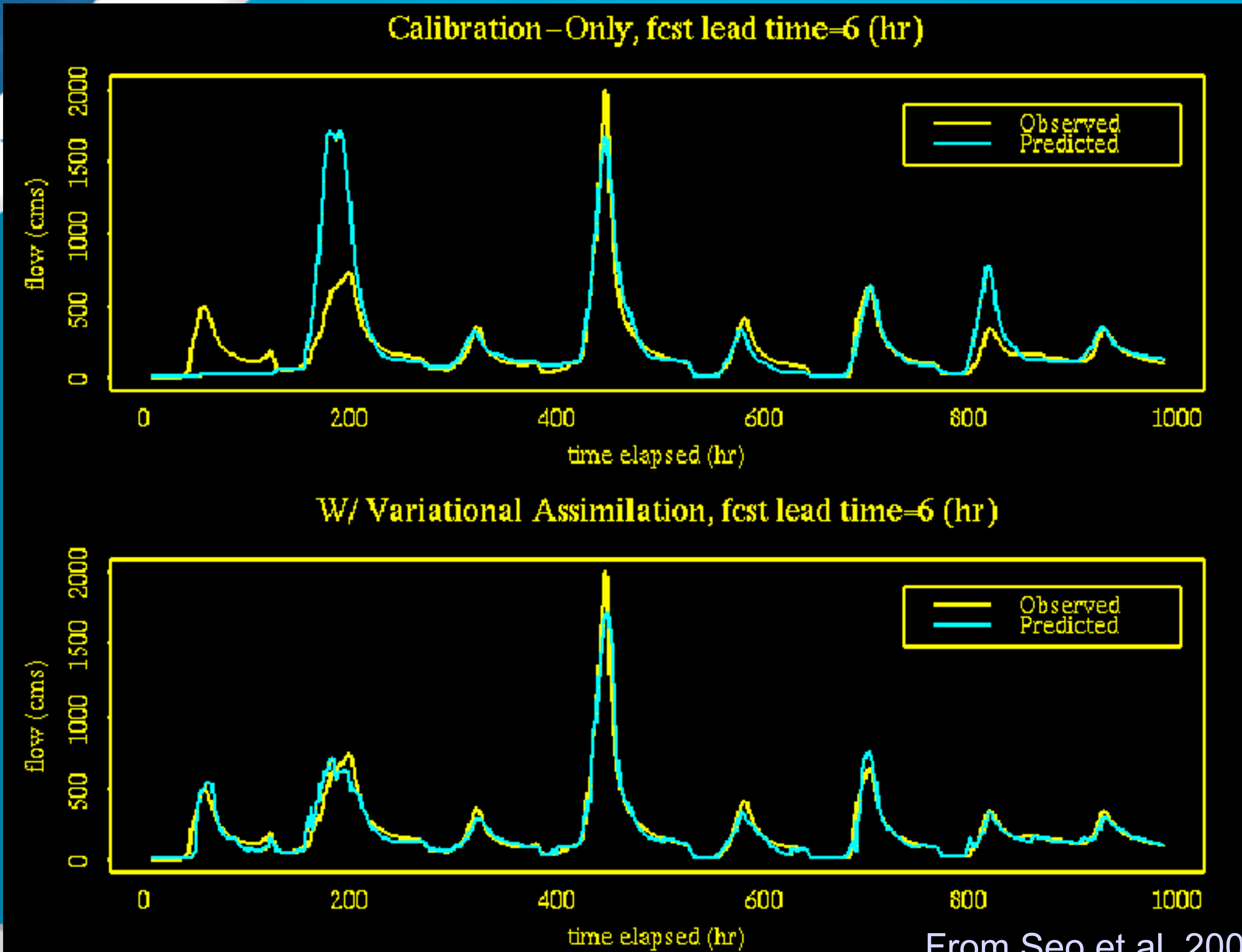
Operational hydrologic Data Assimilation

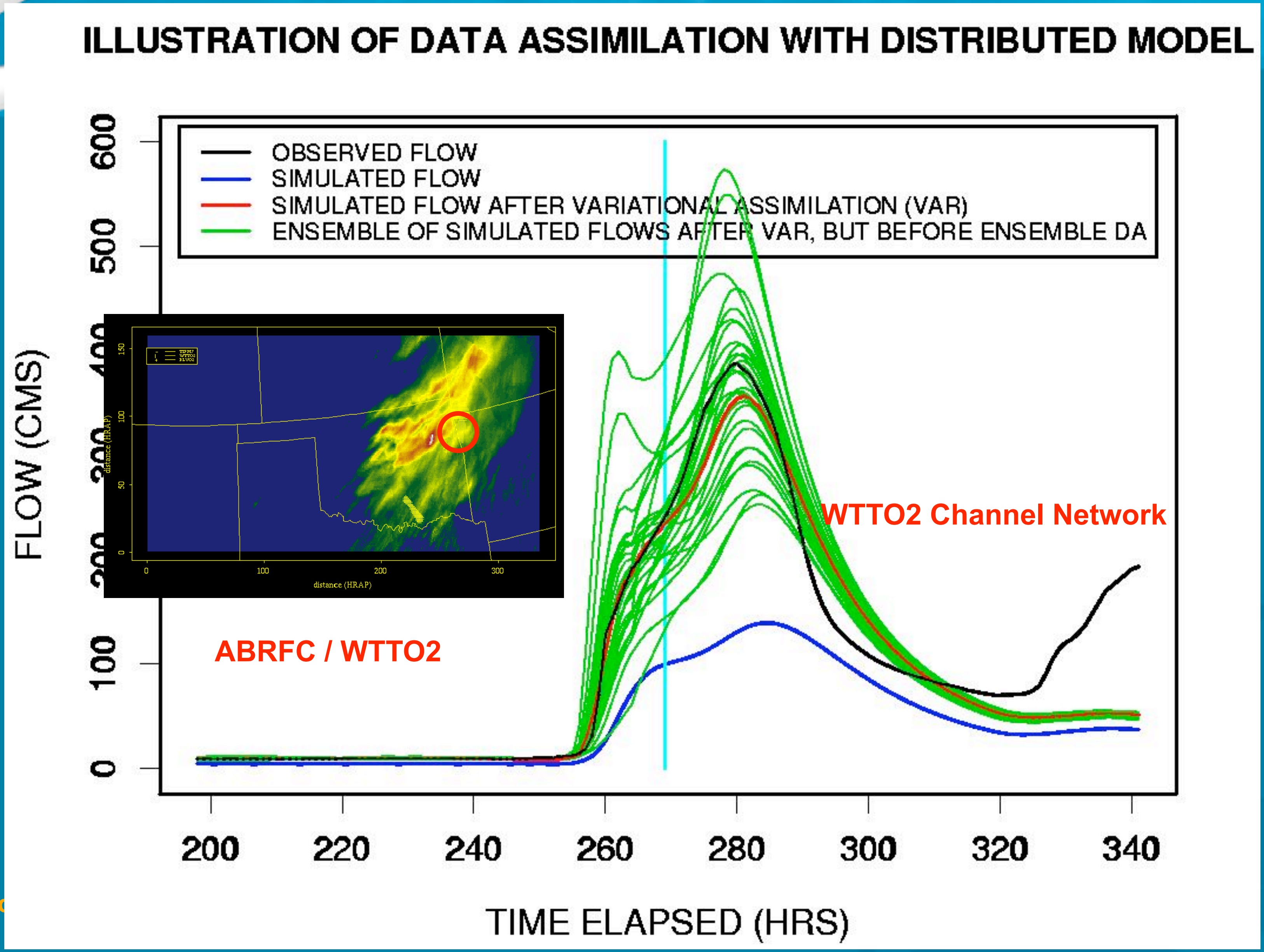


[1] pending assessment



From Seo et al. 2003

Data Assimilation

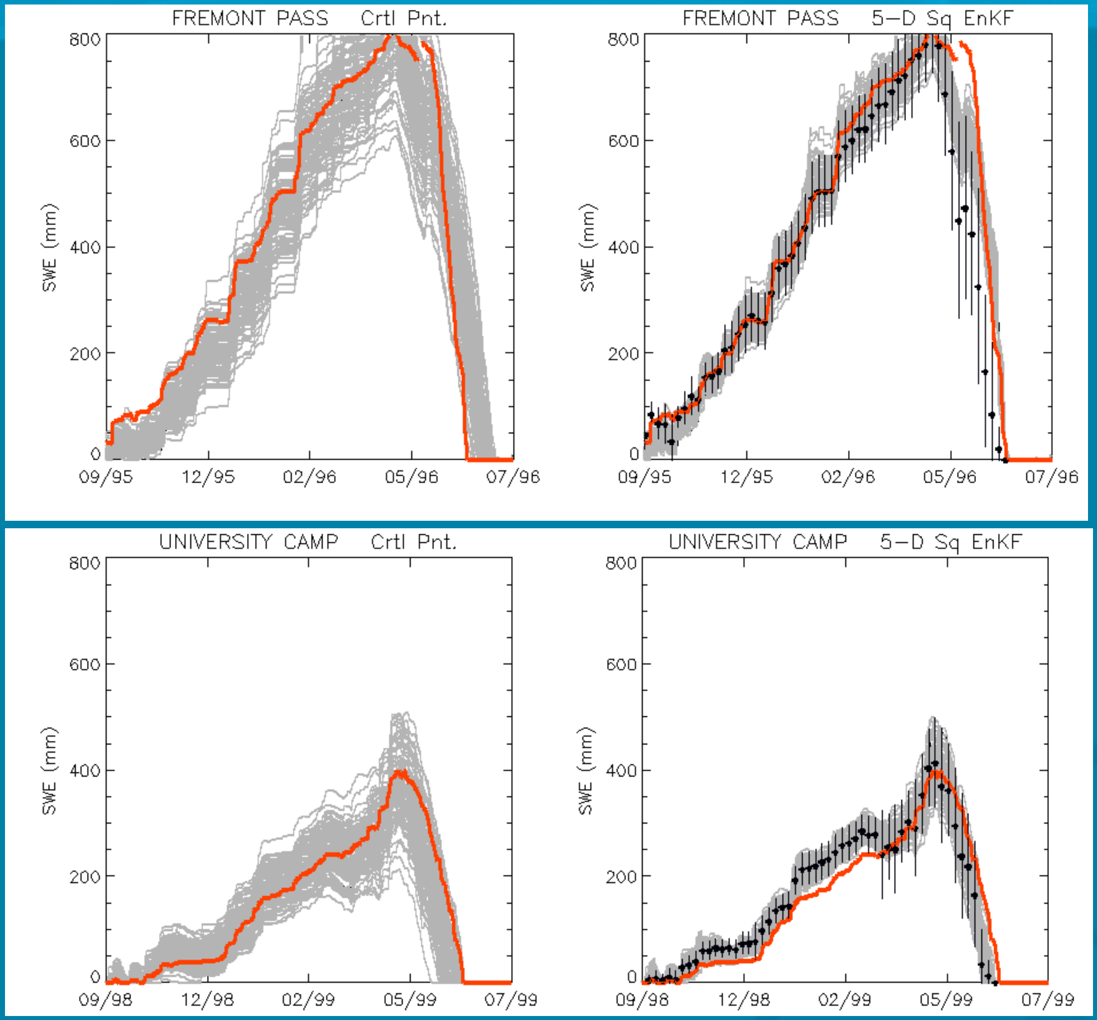


Ensemble Kalman Filter Assimilation of SWE- U. of Colorado, NIWA

Interpolated SWE Mean & Std. Dev

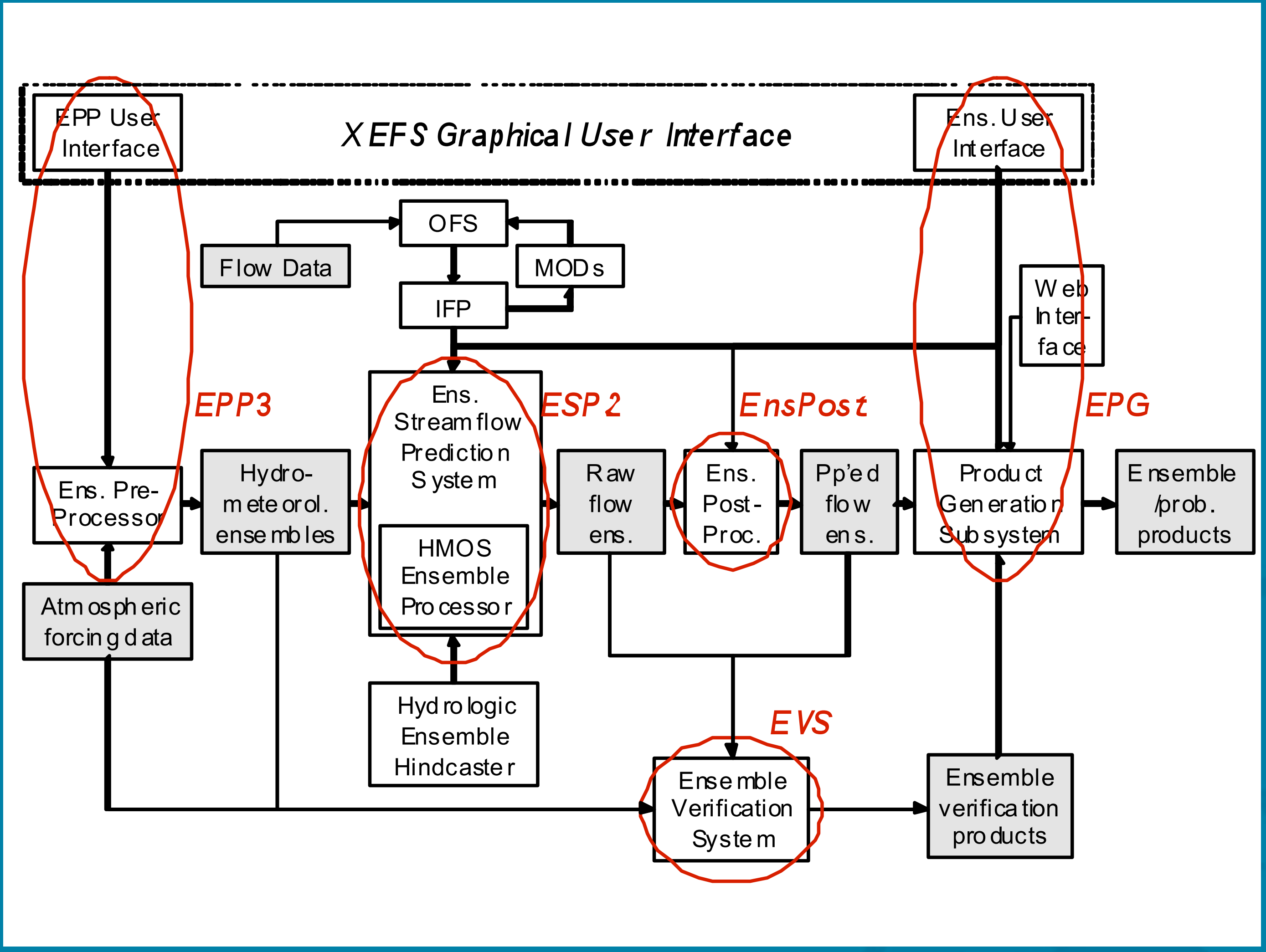
Model

Truth



Slater & Clark, 2006

Ensemble Forecasting: Experimental Ensemble Forecasting System

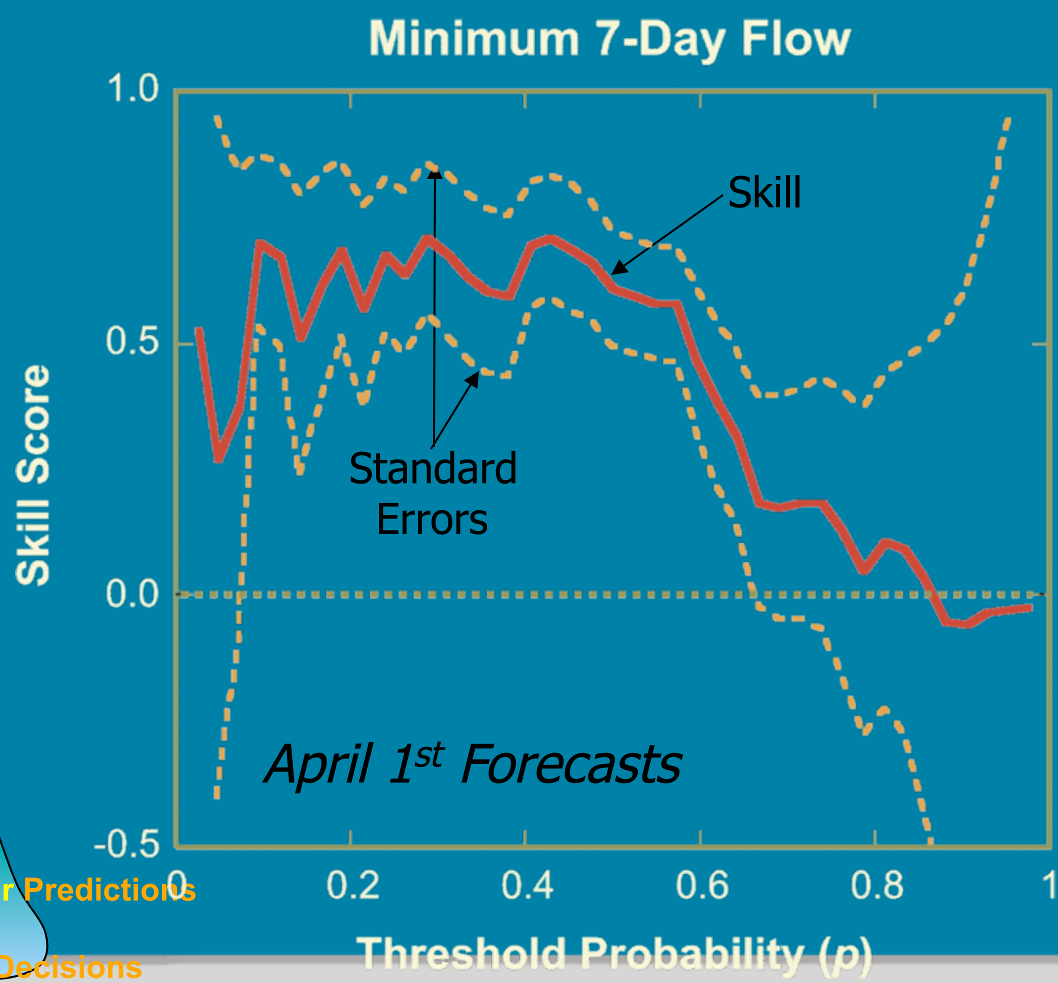


Water Predictions for Life Decisions

Streamflow Forecast Verification

- The 2007 BAMS article by Welles *et al*. “Hydrologic Verification: a call for action and collaboration” clearly showed the need for hydrologic verification
- The Department of Commerce also requested a formal hydrologic verification program
- The only way to know if all the improvements to hydrologic forecasting mentioned earlier are paying off is by having a comprehensive verification system
- OHD, in collaboration with the U. of Iowa, is already developing such a system. It comprises
  - Data Archiving, including forecaster modifications
  - Computing Verification Metrics
  - Uncertainty Analysis
  - Diagnostic and Prognostic Verification
  - Communicating results

Ensemble Forecast Skill- Iowa Institute of Hydraulic Resarch



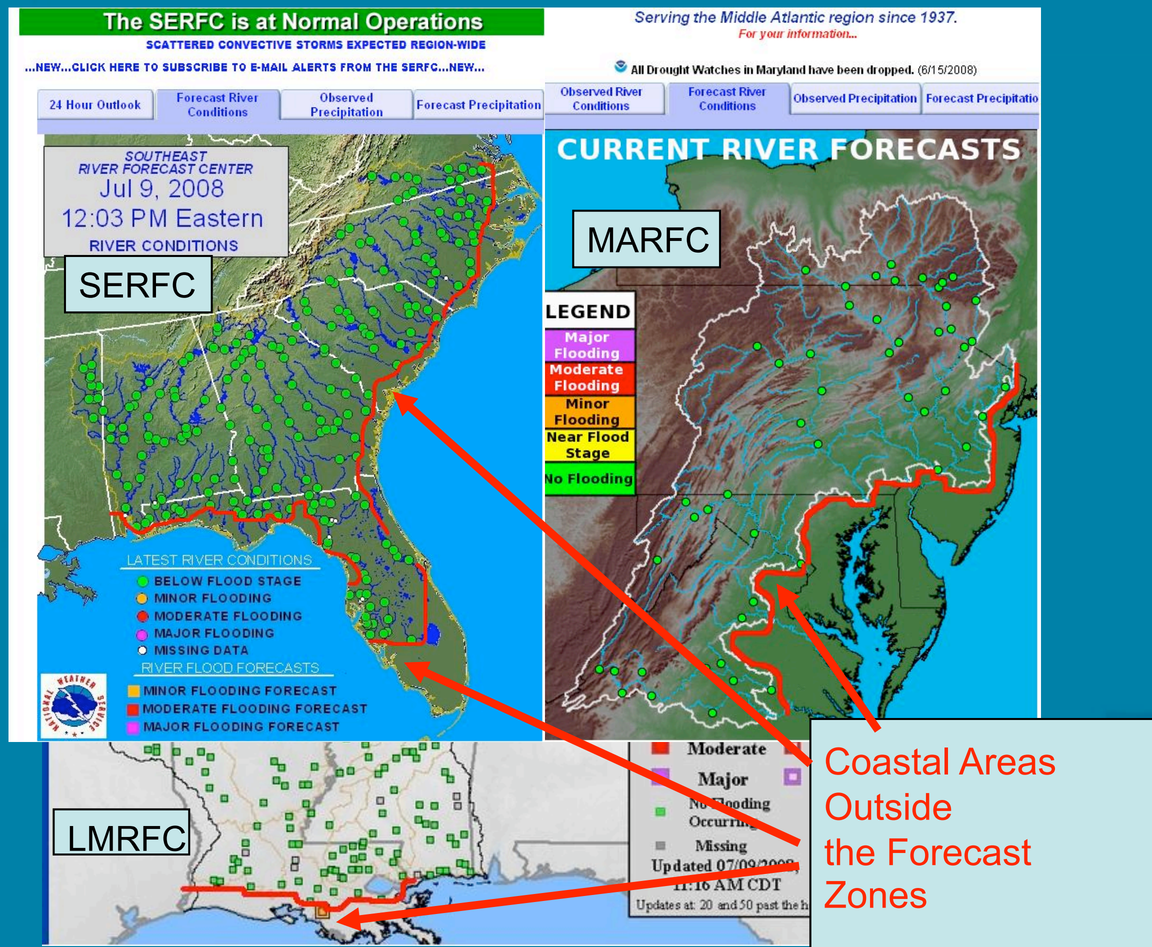
- Skill depends on the threshold
- Uncertainty is greater for extremes
- Summary measures describe attributes of the function

IIHR Hydroscience & Engineering

Hydraulics Group

- Where we want to be:
  - Integration of river models with estuary/ocean models
  - Use of 2Dimensional models where required
  - Coupled Surface-groundwater models
  - Water quality forecasting models: temperature, contaminants, nutrients

Hydrologic Forecasting in the Coastal zone



Water Predictions for Life Decisions

Part II: The Community Hydrologic Prediction System
CHPS

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Office of Hydrologic Development
National Weather Service

Earth Systems Research Laboratory
April, 2009

Why CHPS?

NWSRFS is a great architecture that was developed for use on mainframe computers

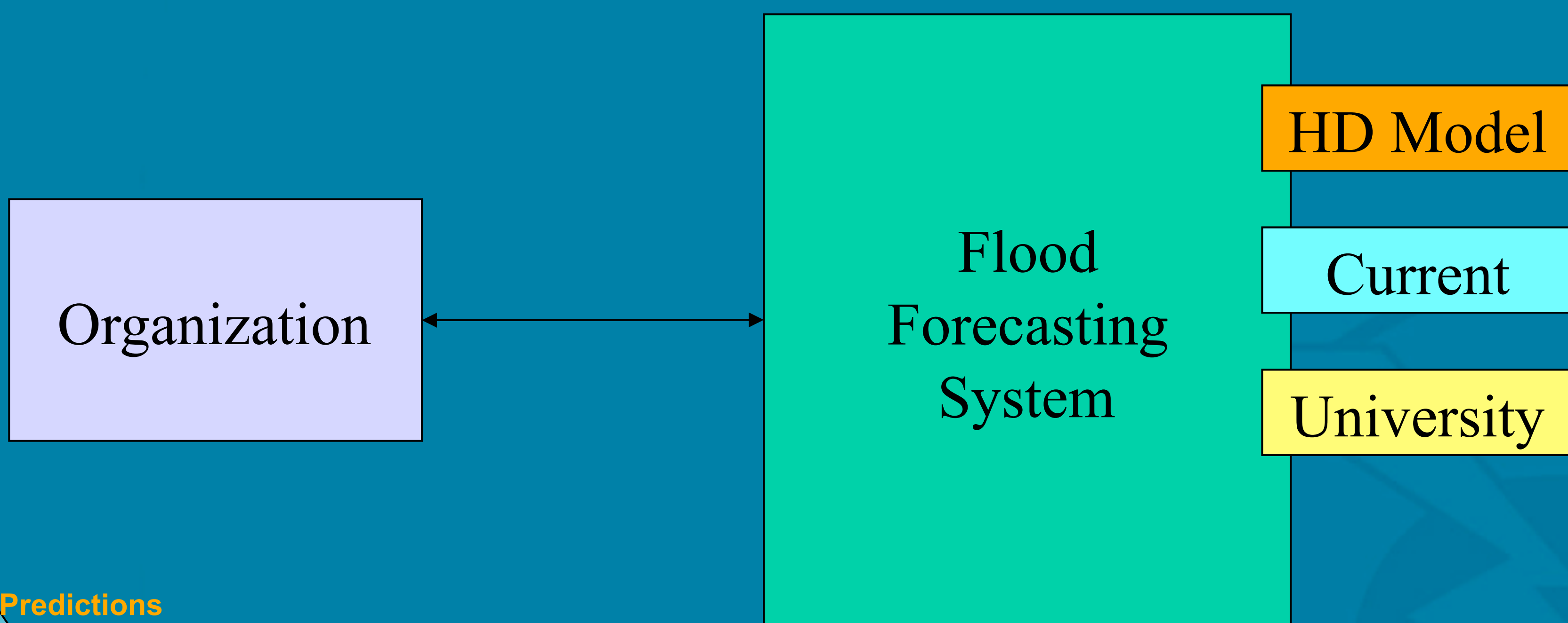
- lacks modern modularity
- difficult to add new models and techniques
- inhibits collaboration and research to operations
- very fast

CHPS will allow:

- greater ease in implementing new models
- greater collaboration with agency partners, universities, international community
- probably not as fast

Open System…

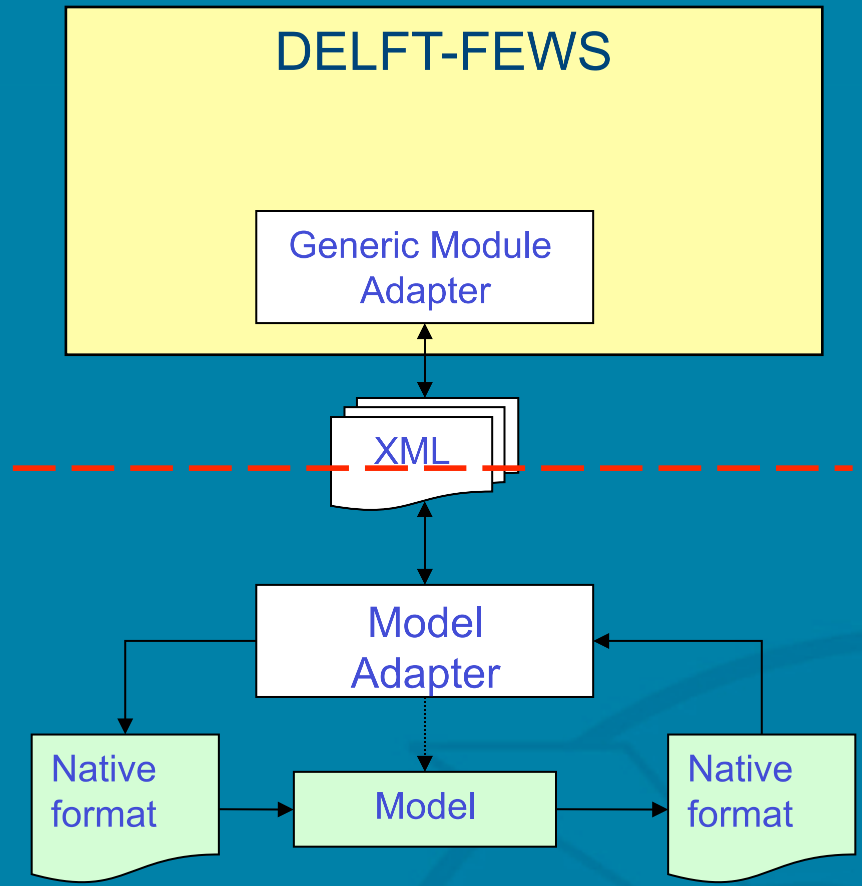
- No implications when introducing new model concepts
- Maintain current models/investments
- Easily introduce new advances



Open interface to models

No model intelligence in DELFT-FEWS

Model intelligence vested in model adapter



Water Predictions for Life Decisions

Implementation Strategy

Clear planning and execution

- Gap analysis for essential operations
  - Use of existing calibrated parameter sets is essential
- Preprocessing and post-processing utilities
- AWIPS II integration
- Staff training
- Change in conditions of work (NWSEO)
- Technical support
- RFC contributions (individual, groups, regions)
- Many others…

Implementation Strategy

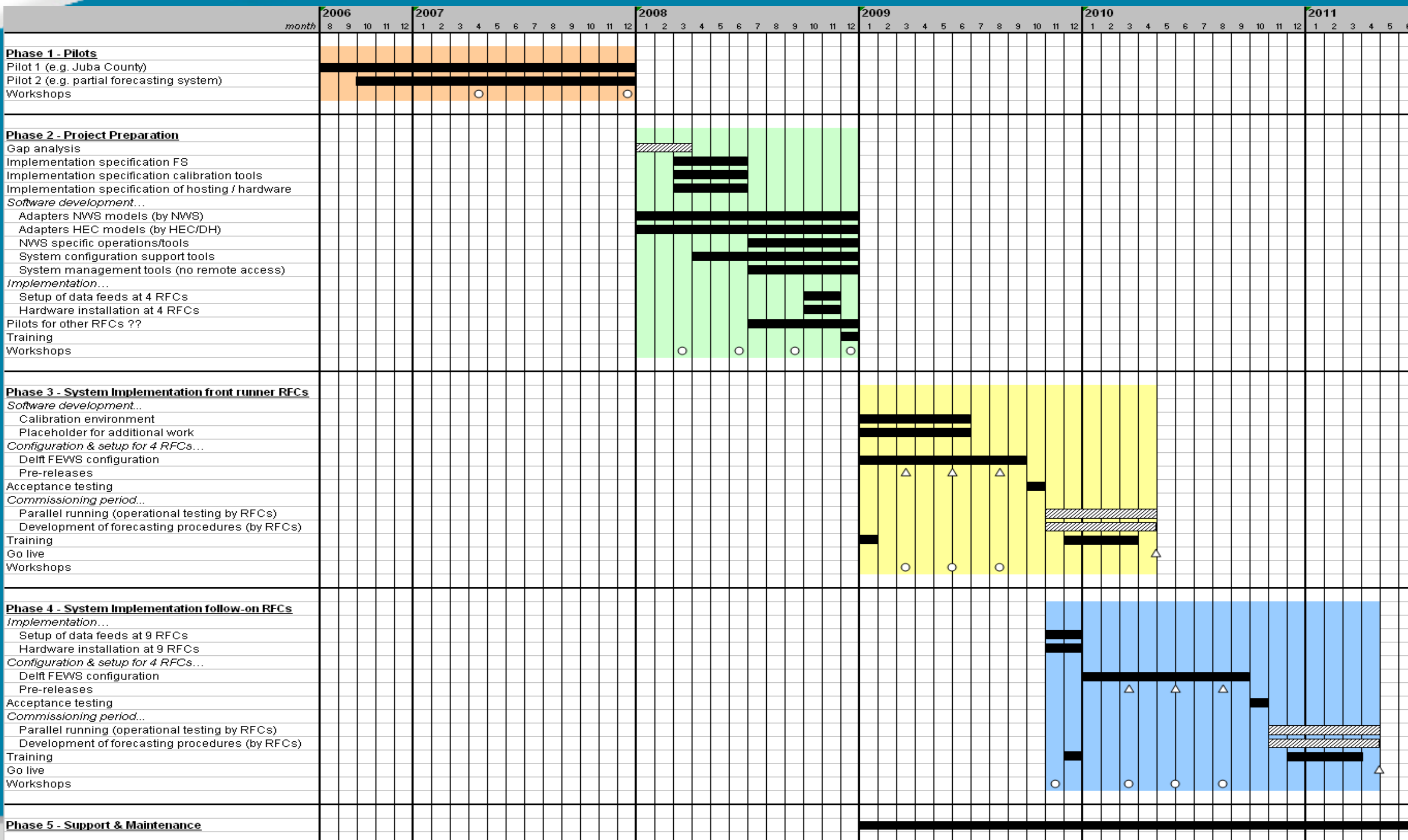
Two tiers of deployment

- CAT RFCs (AB, CN, NE, NW)
  - Initial hardware delivery in October 2008
  - Initial migration software and training in January 2009
  - Operational hardware delivery summer 2009
  - Parallel operations by October 2009

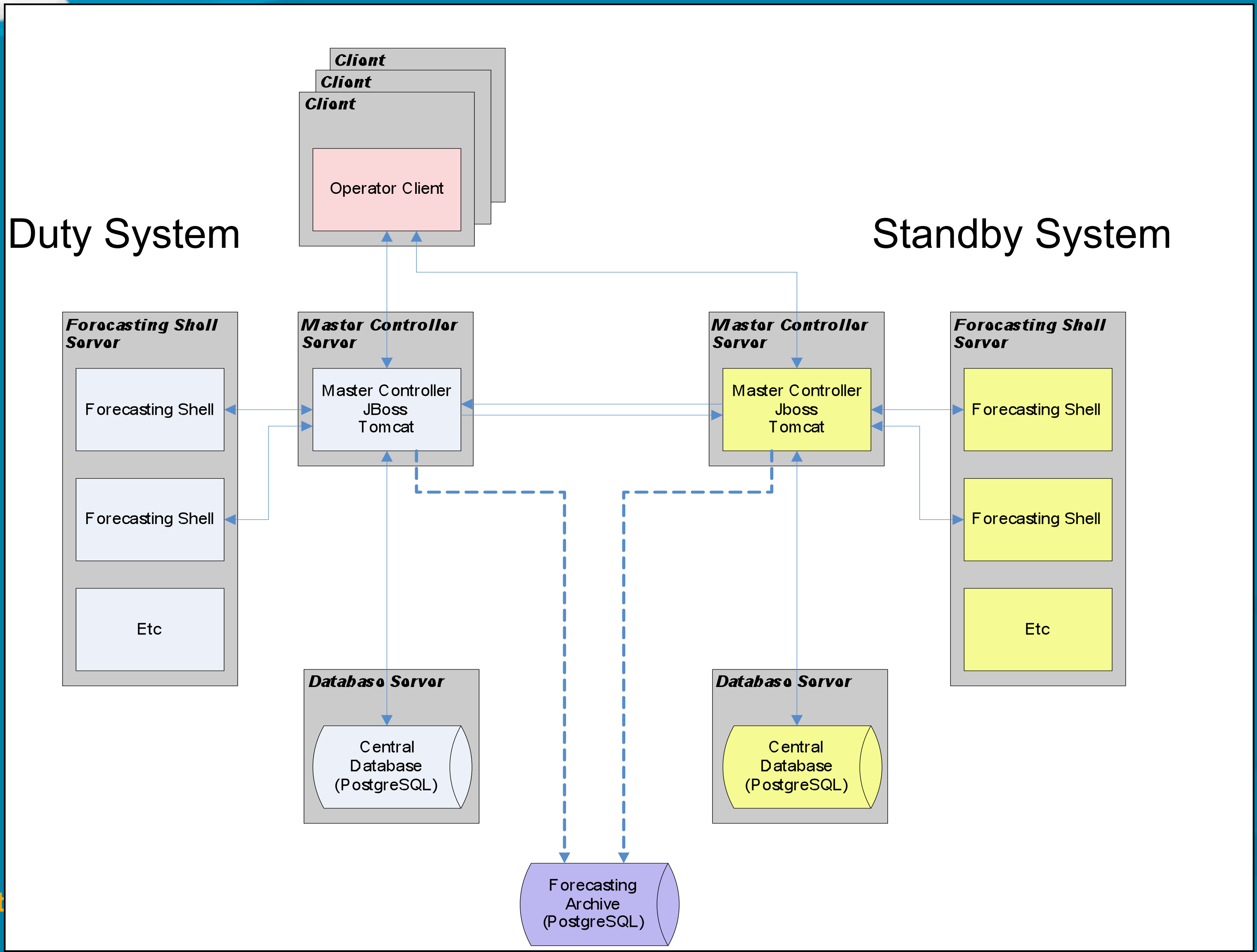
- Remaining 9 RFCs
  - Initial hardware delivery in October 2009
  - Migration/Systems training – Fall 2009
  - Migration begins January 2010
  - Parallel operations by October 2010

RFCs not required to drop NWSRFS until “fully ready”

Project Timeline

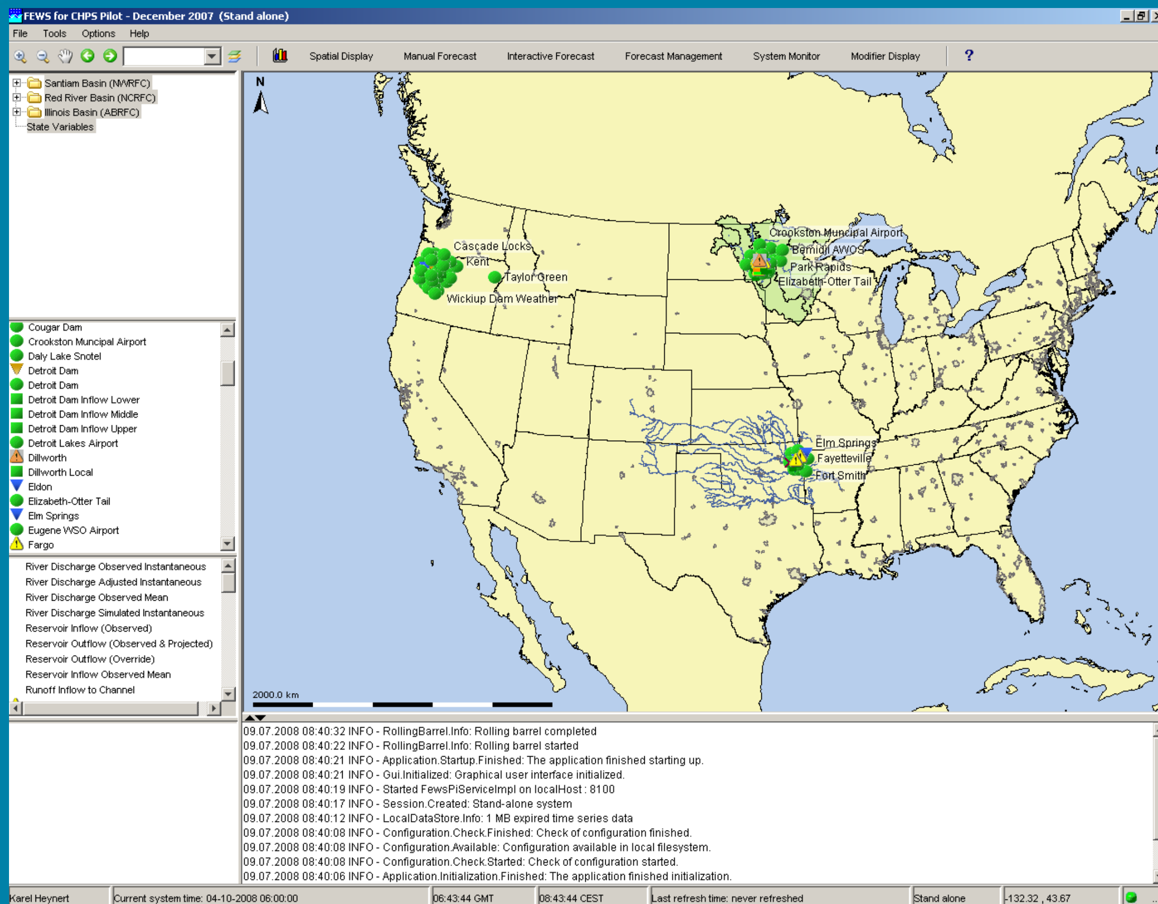


FEWS Hardware Infrastructure

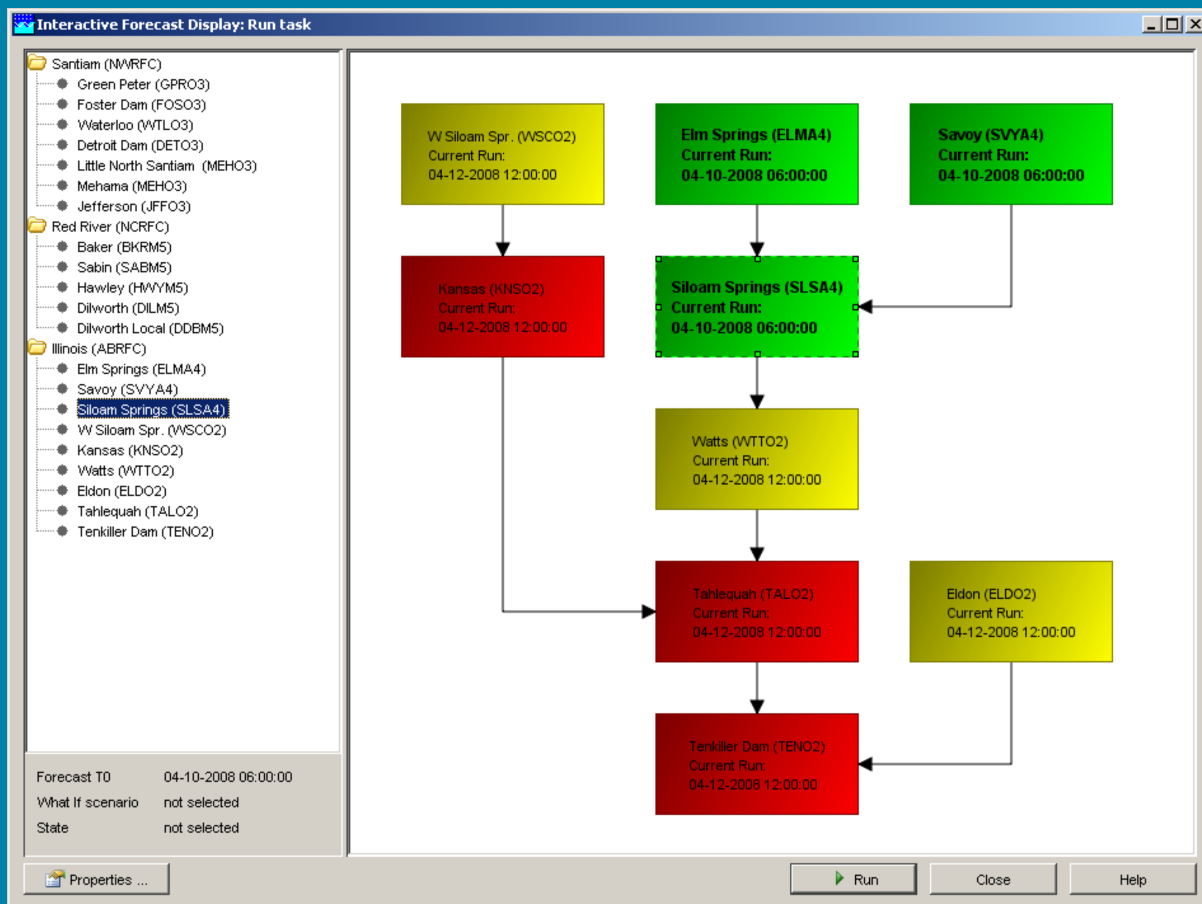


Water Predict for Life Decisions

Main Map Display

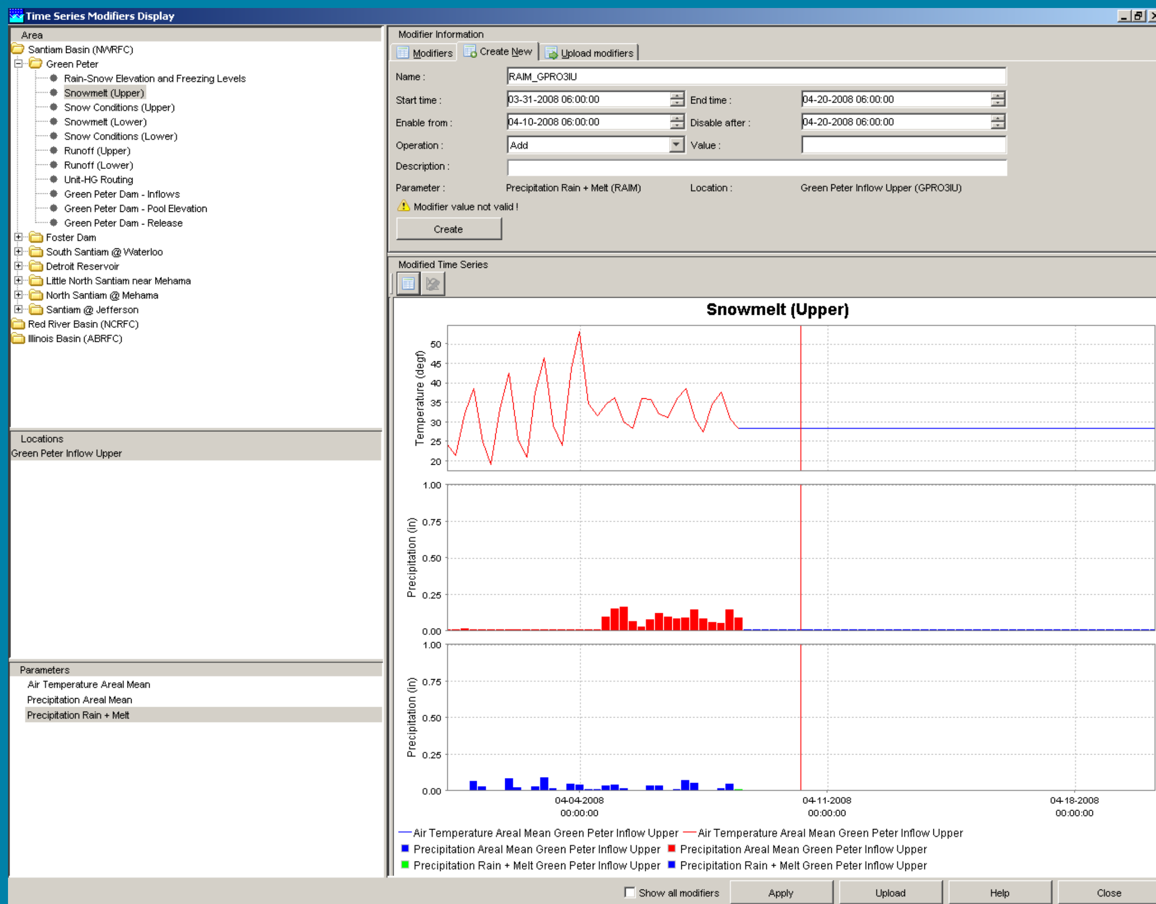


Interactive Forecasting Display



Water Predictions for Life Decisions

Time Series Modifier Display



Water Predictions
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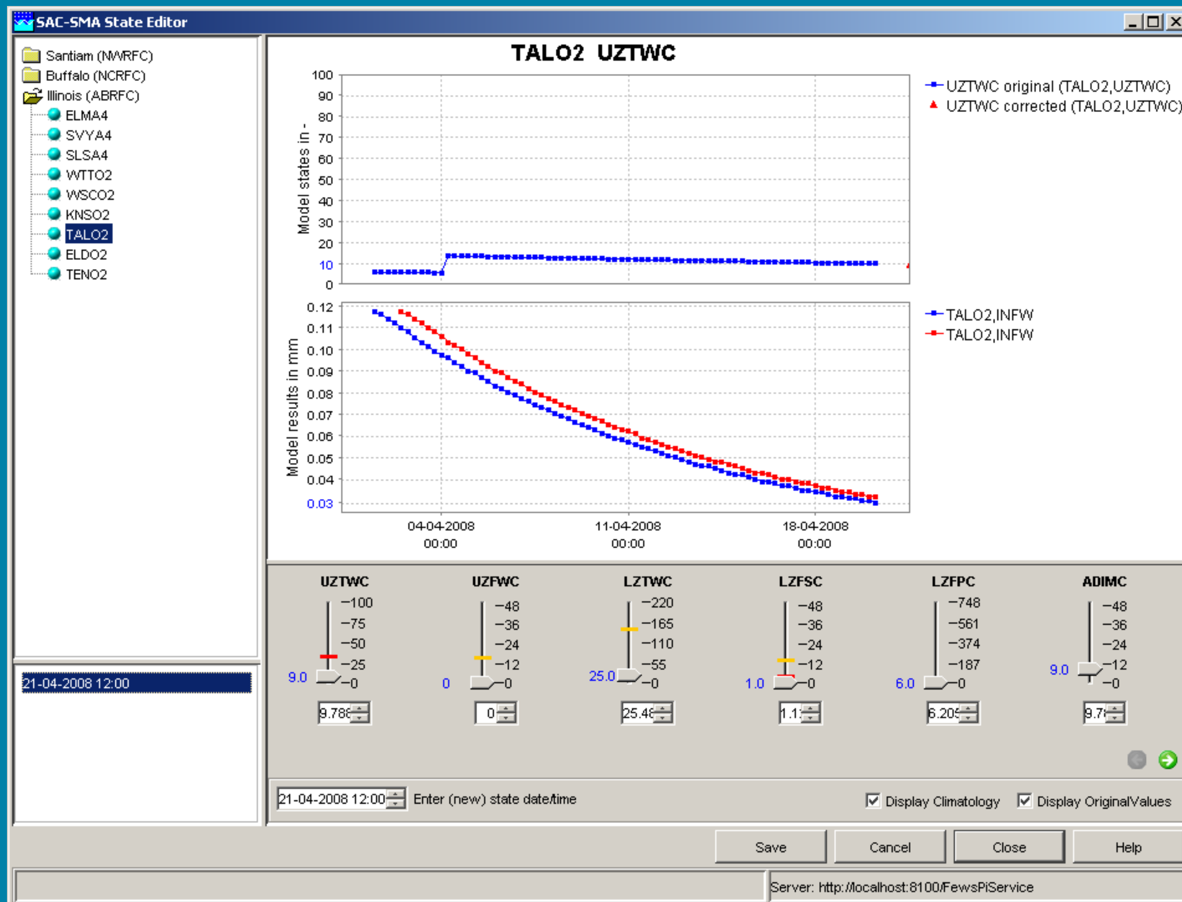
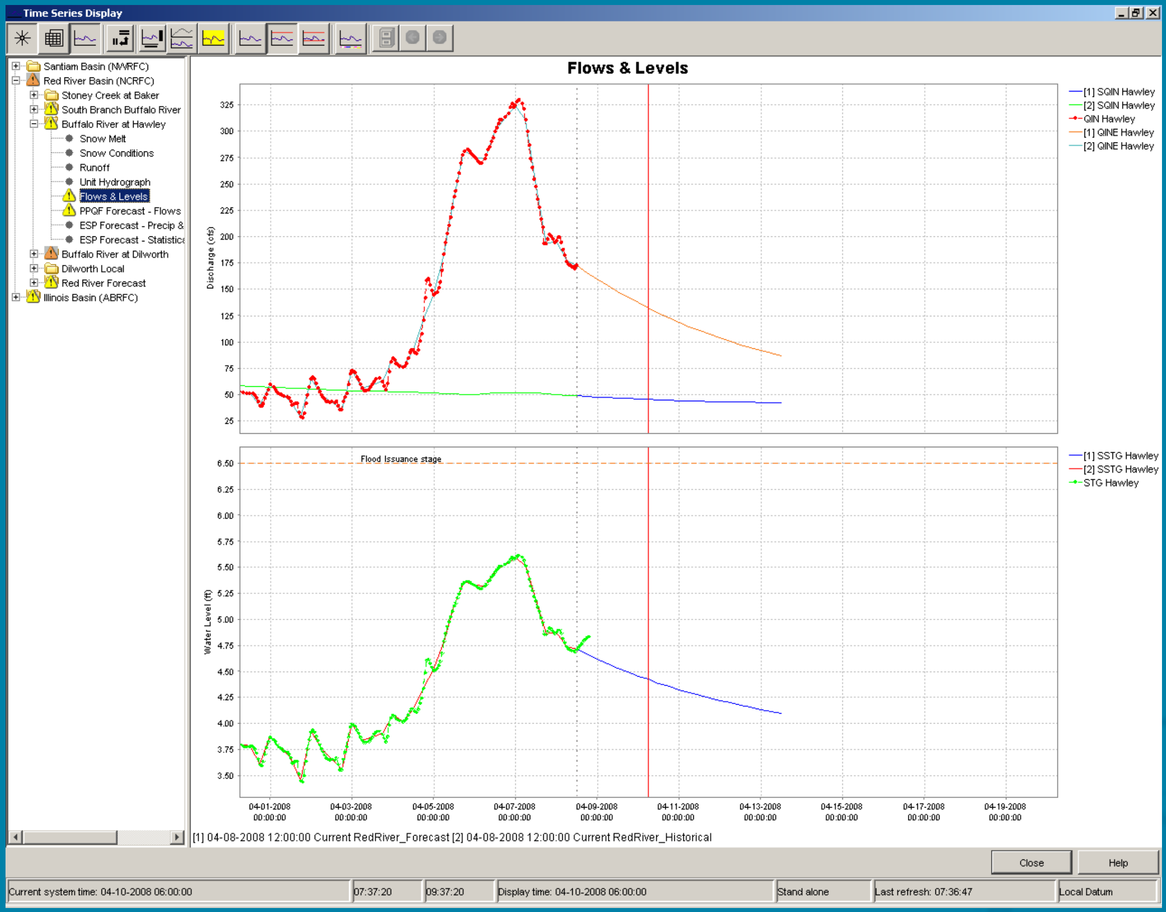
State Modifier Display

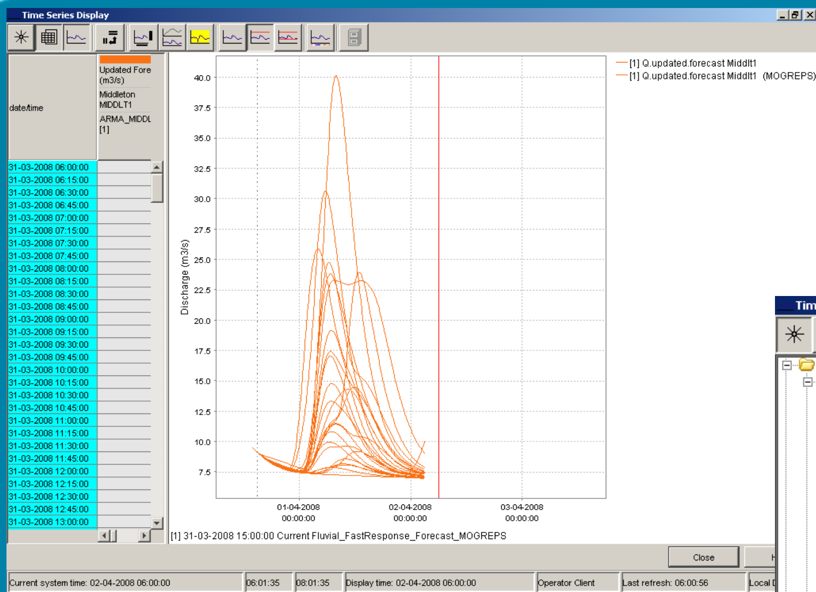


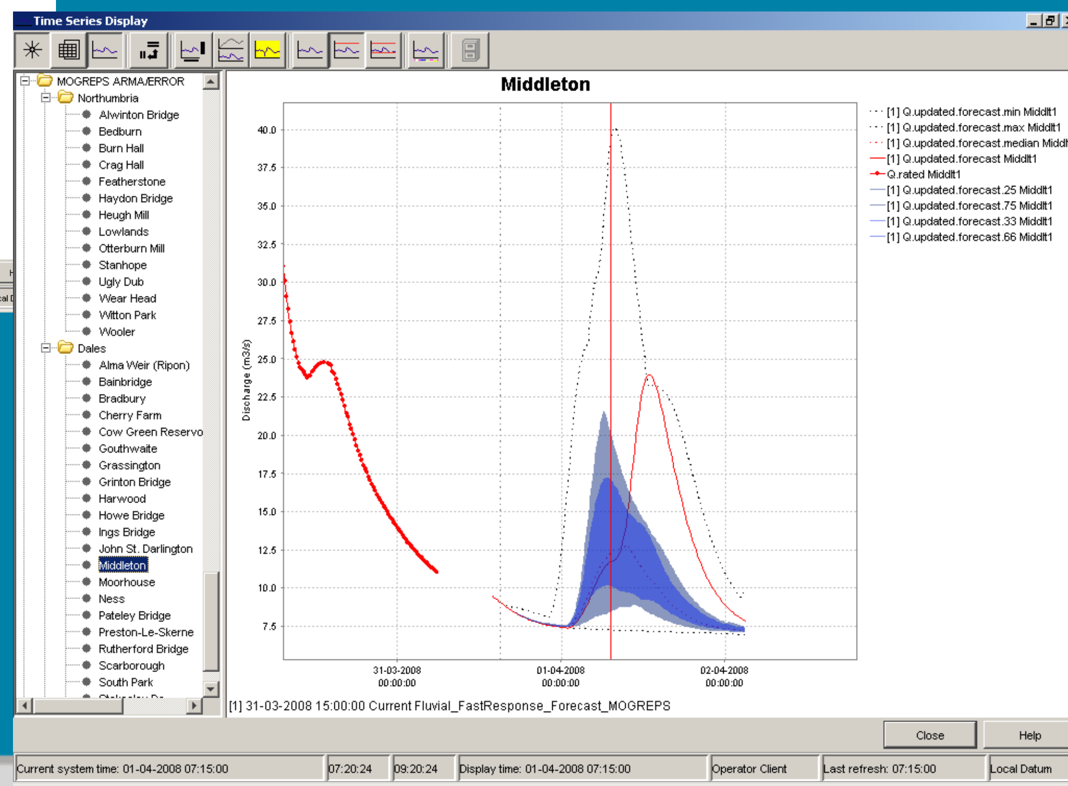
Time Series Display



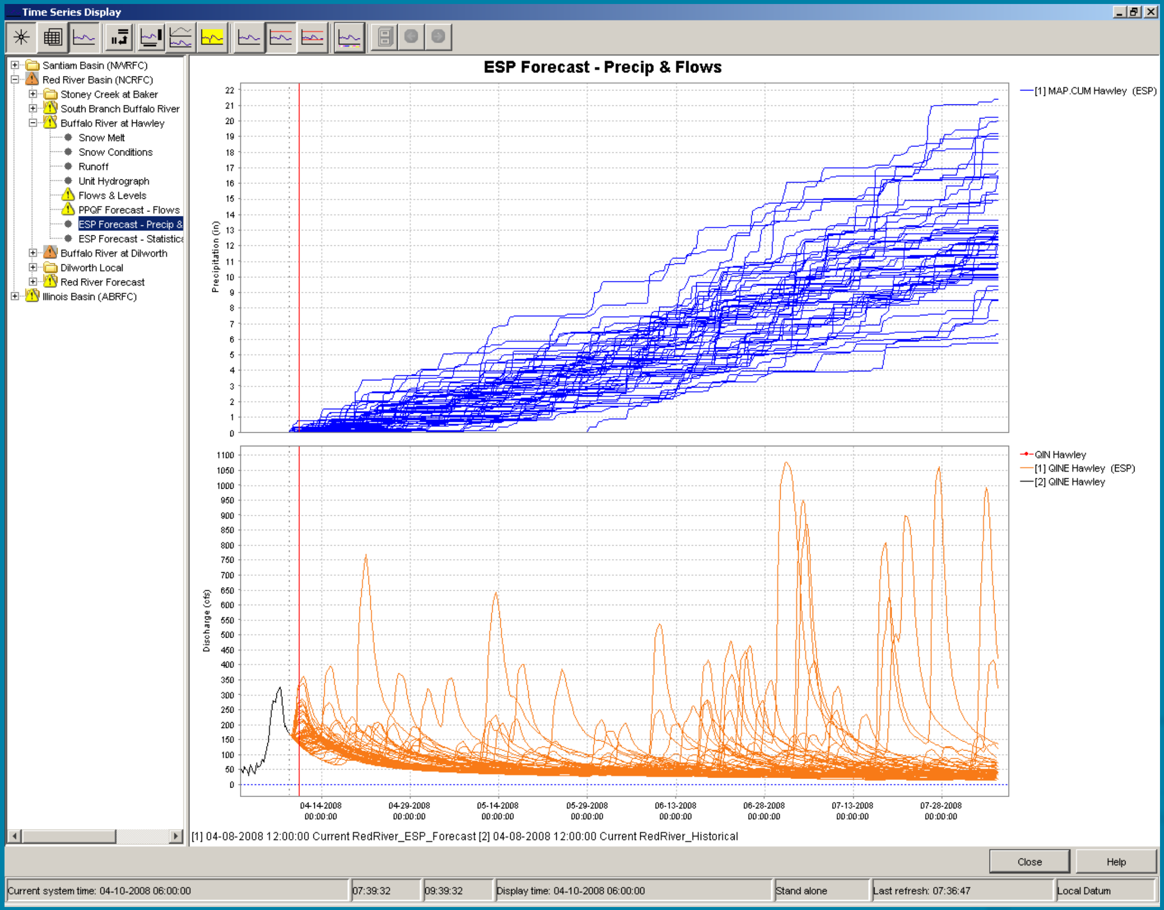
Water Predictions for Life Decisions

Time Series Display (Probabilistic)





Time Series Display (ESP)



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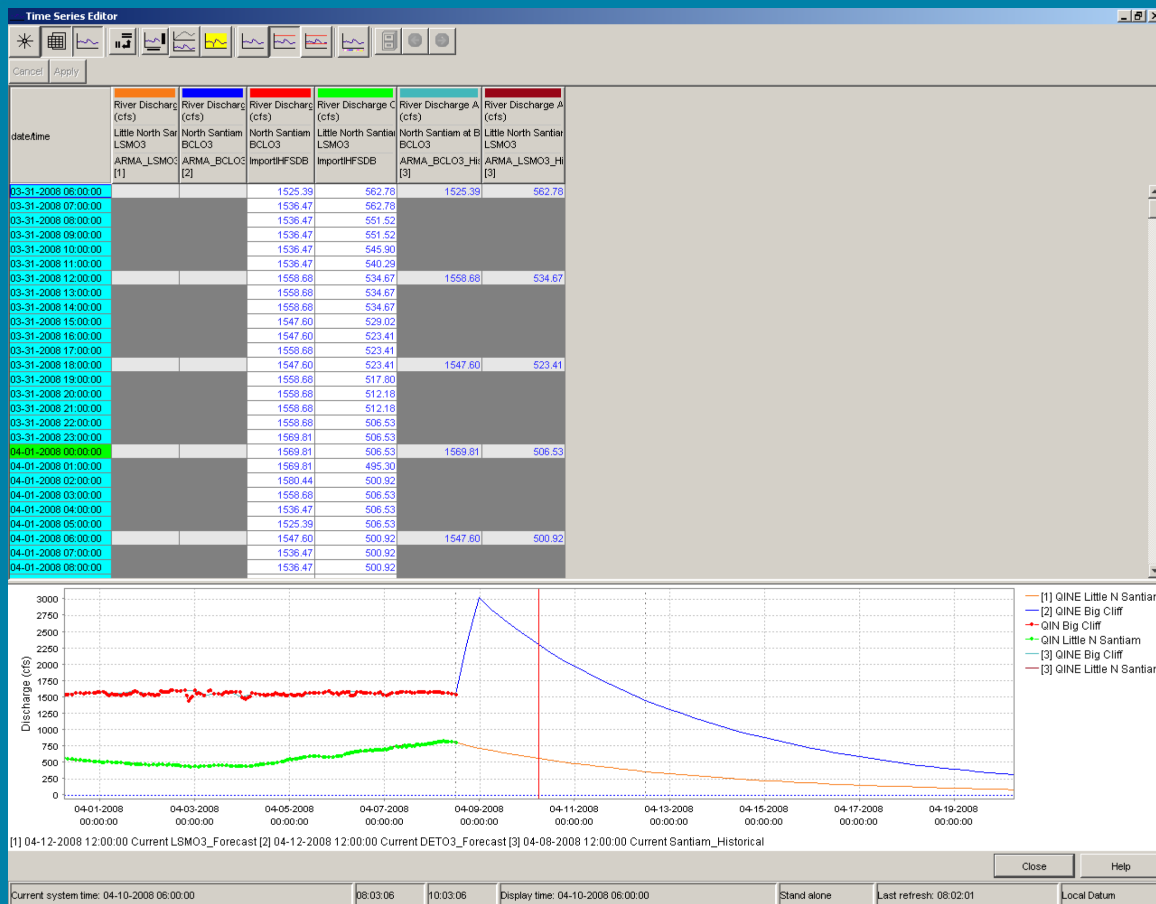
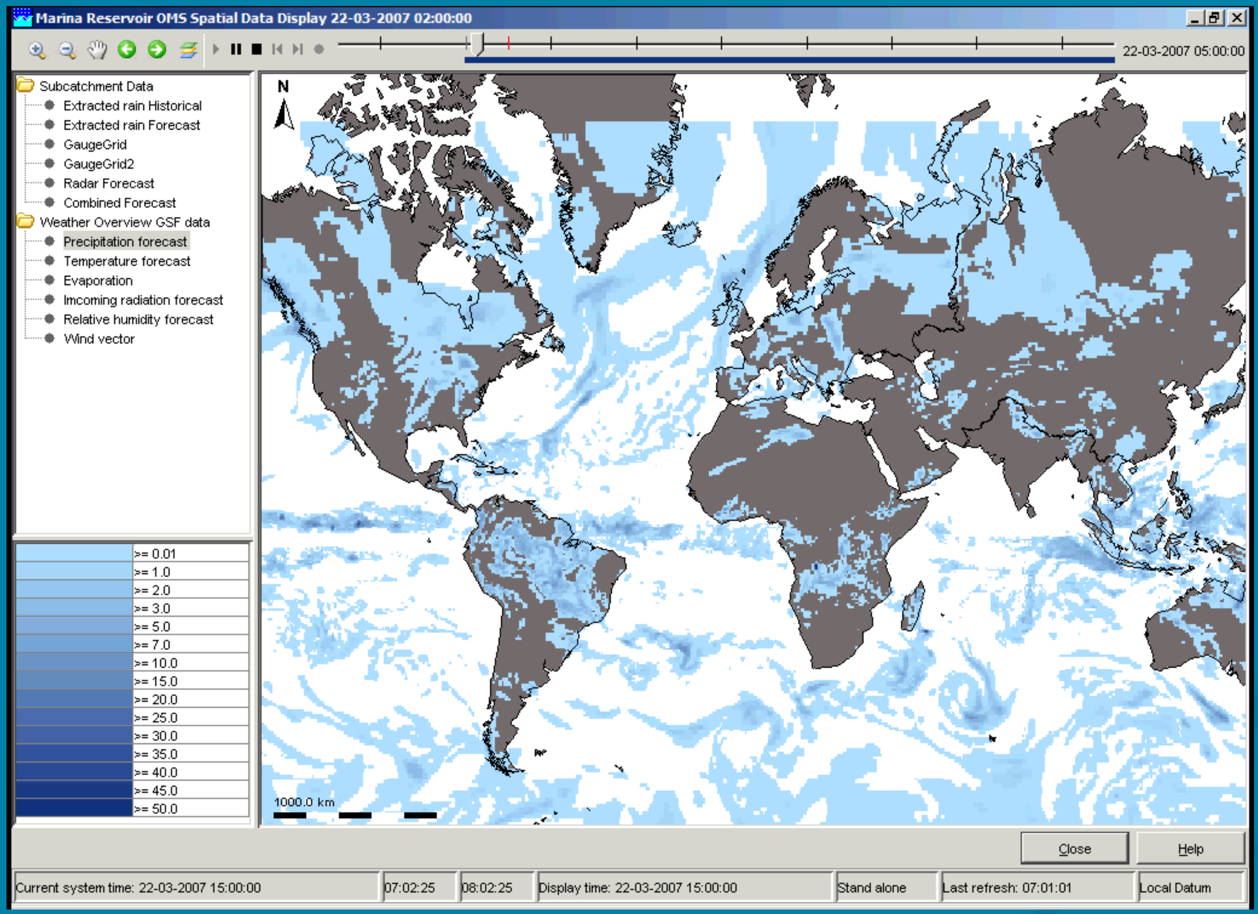
National Weather Service

Time Series Editor



Water Predictions for Life Decisions

Spatial Display (NWP)



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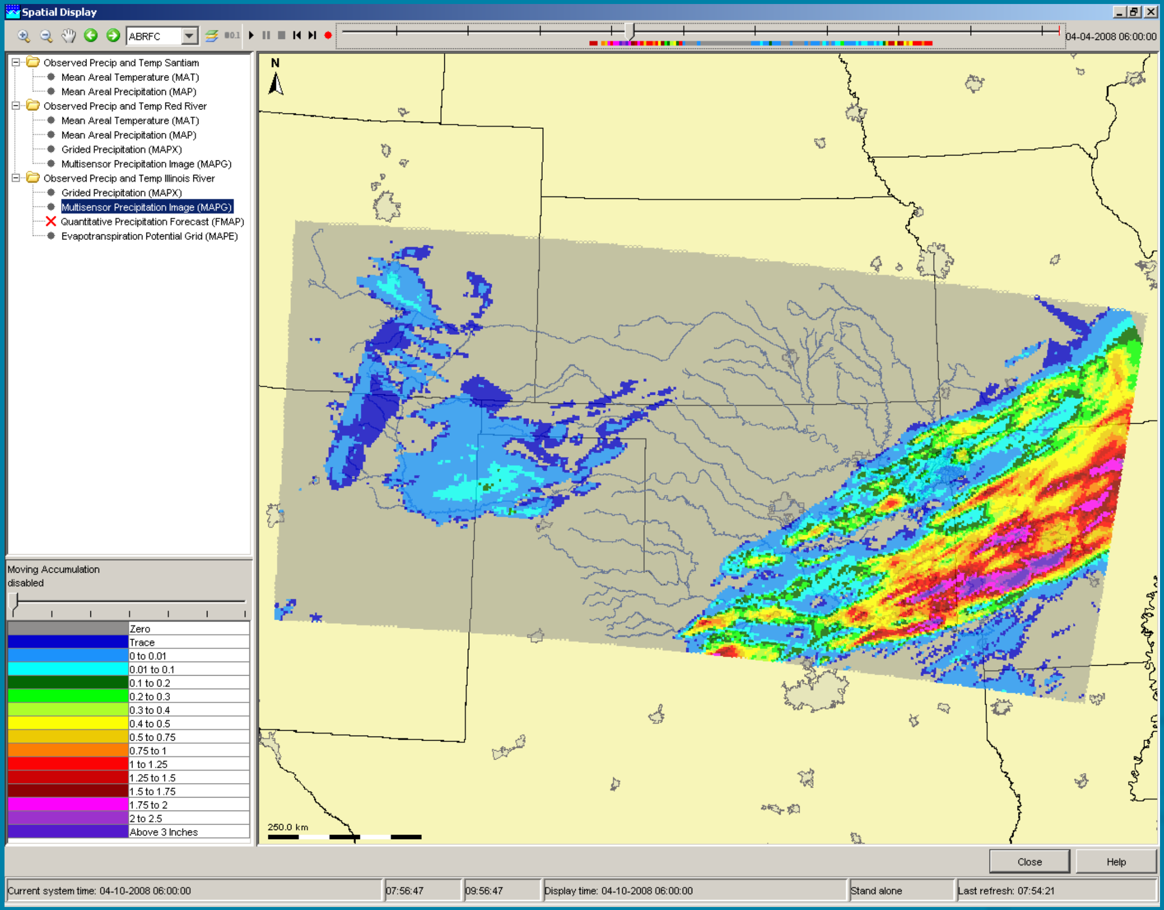
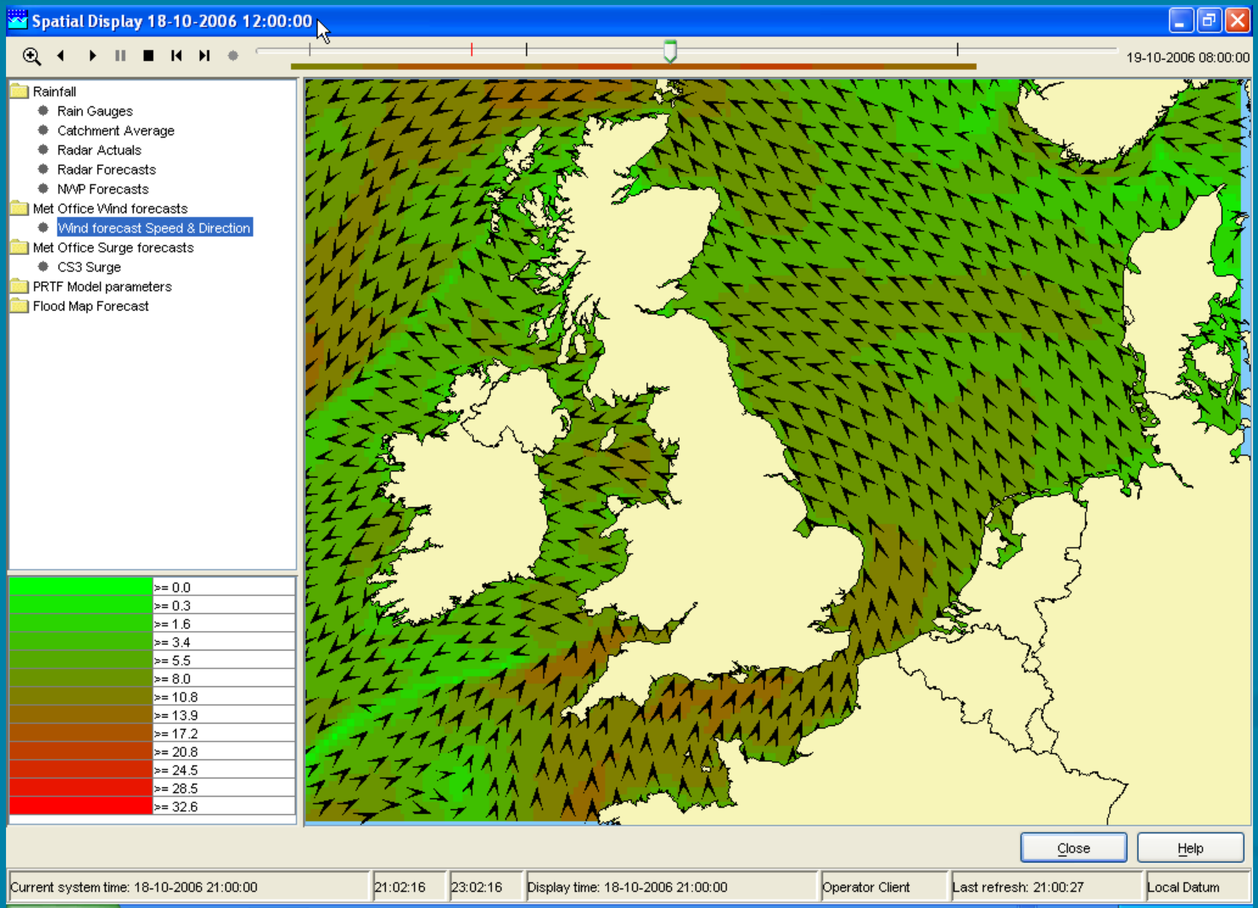
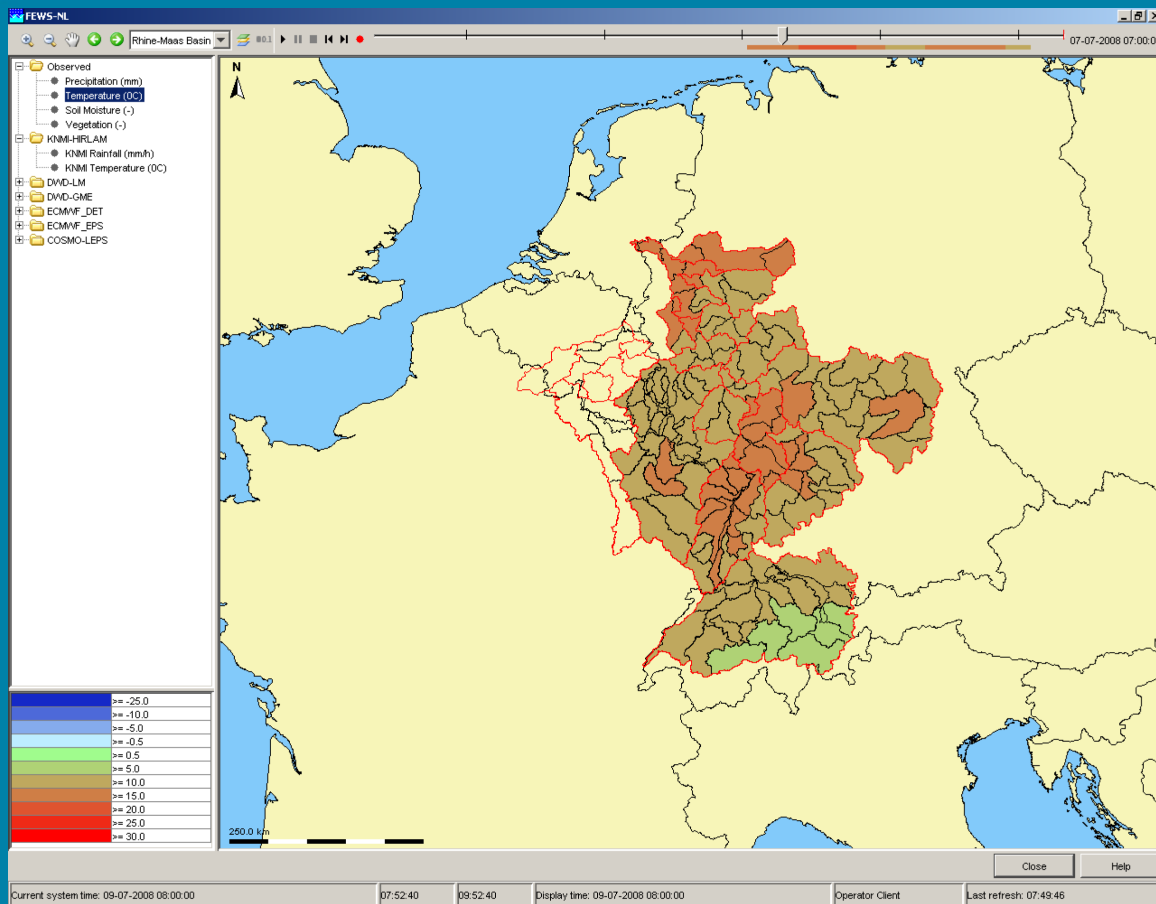
Spatial Display (Multi Sensor)



Spatial Display



Spatial Display (Catchments)



Water Predictions
for
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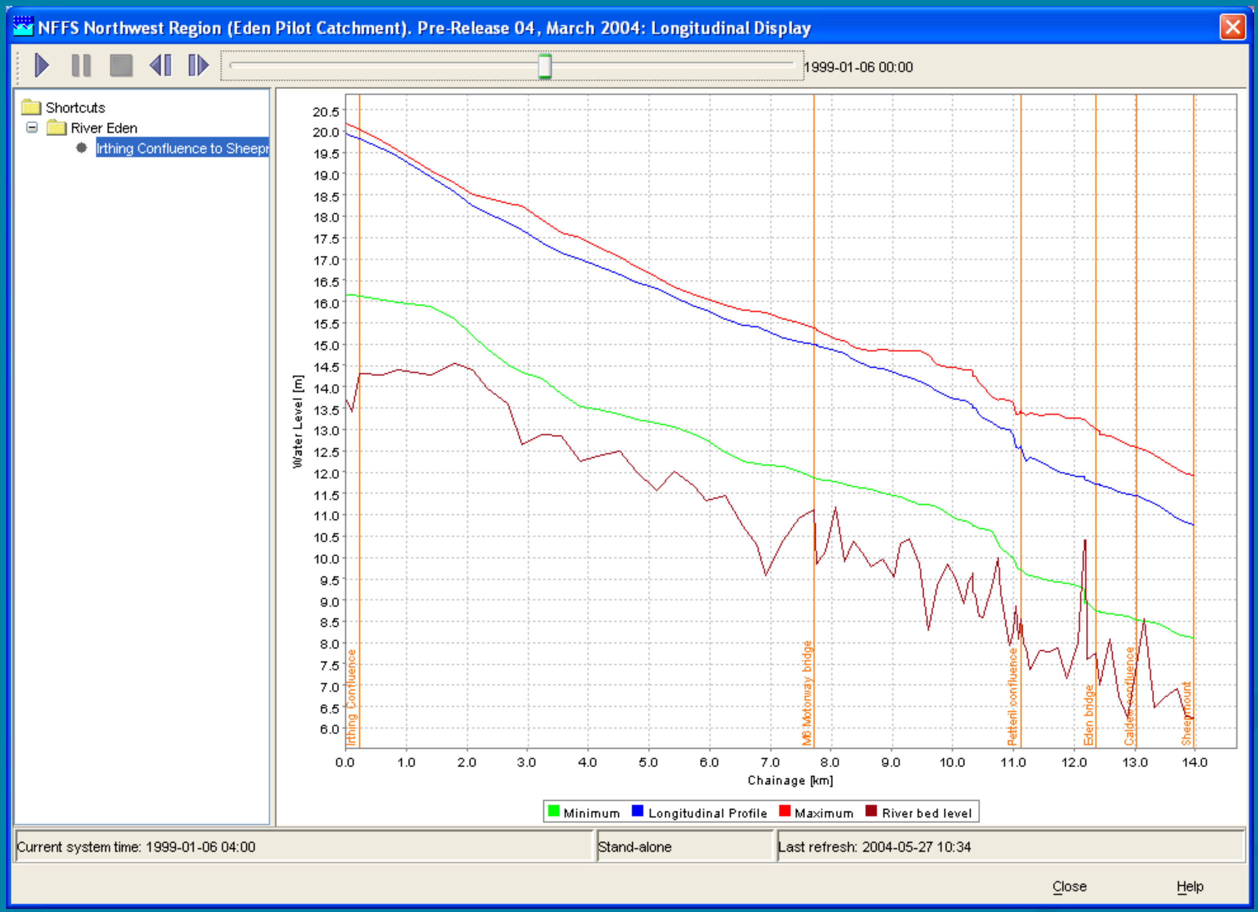
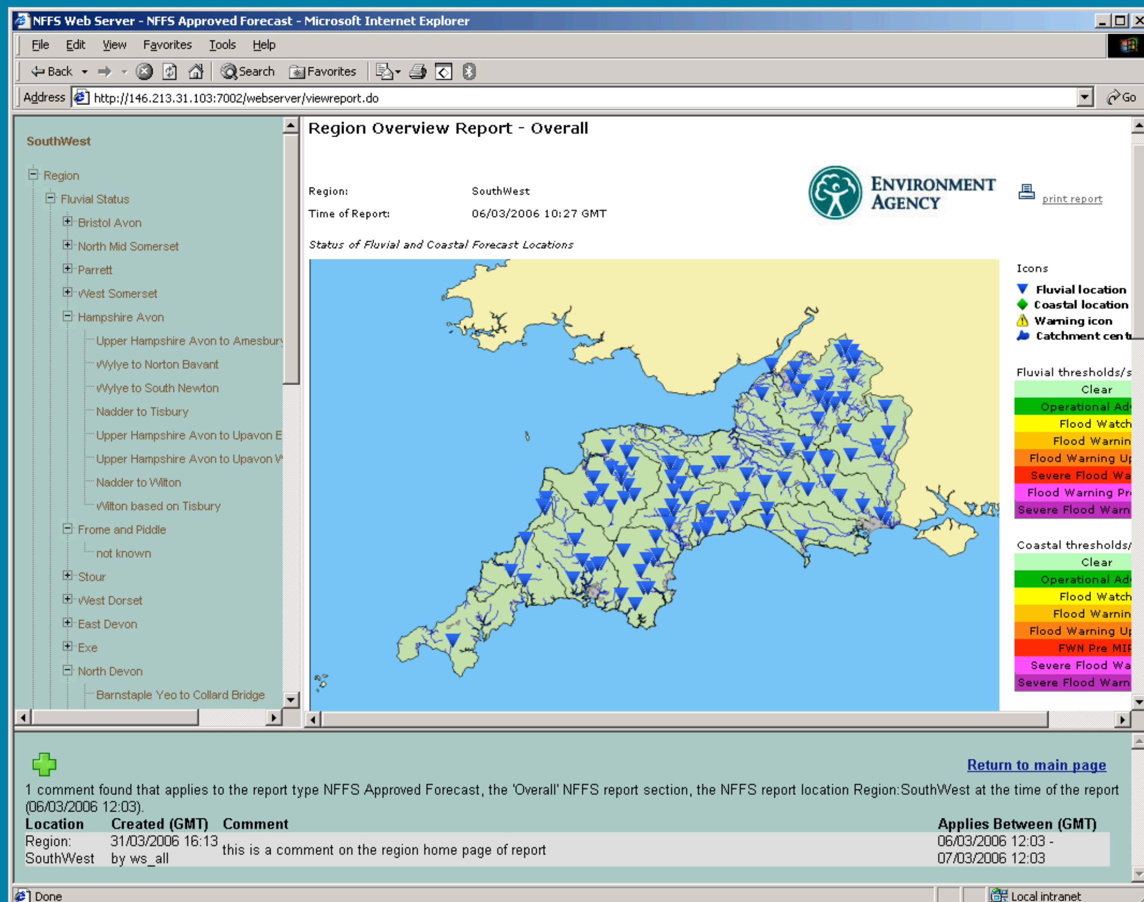
Longitudinal Display



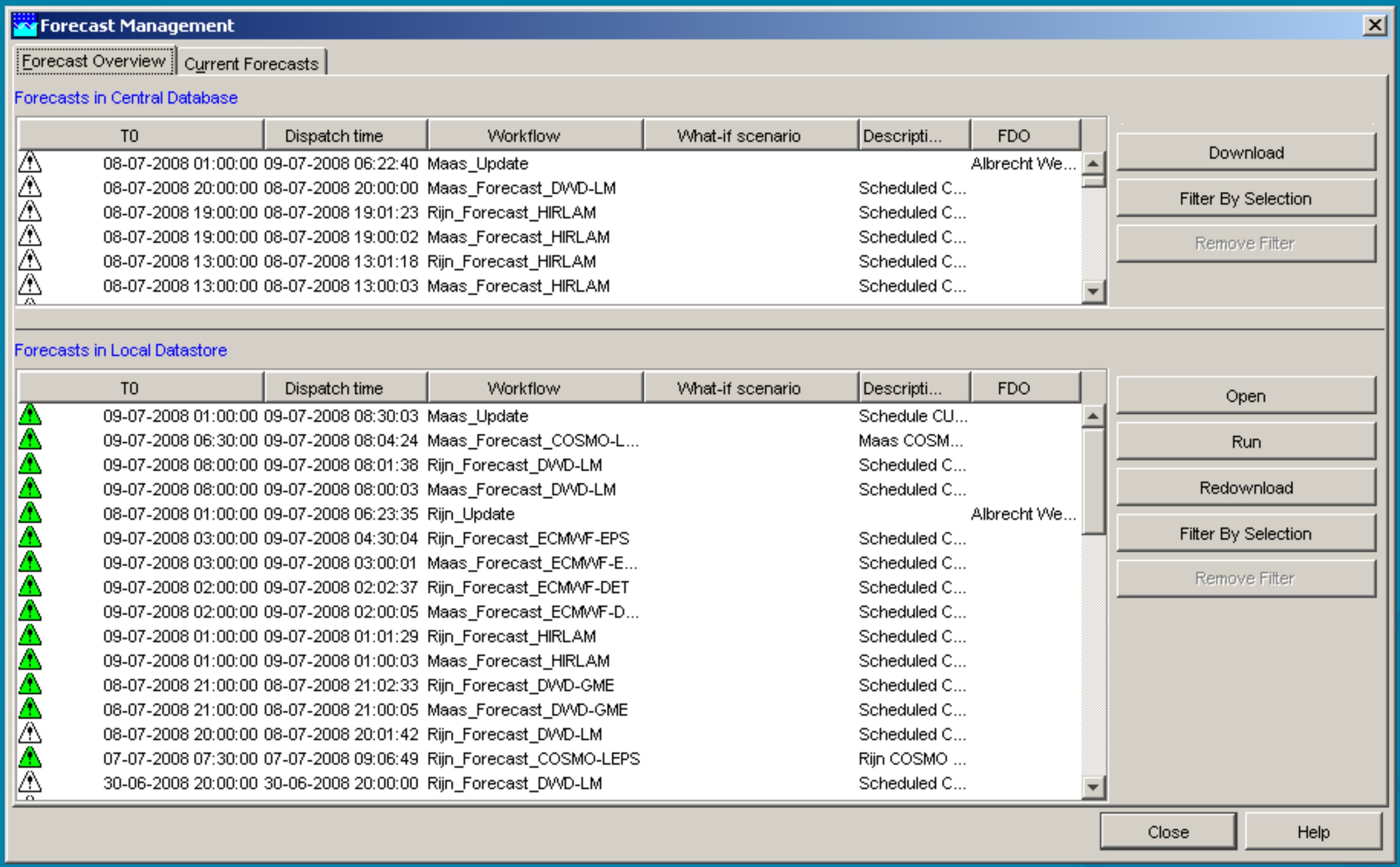
Water Predictions for Life Decisions

Web Server & Web Reports



Water Predictions for Life Decisions

Forecast Manager



System Monitor (Log Browser)

System Monitor   Profile for full synchronisation between Operator Client and Master Controller.

Log Browser | Live System Status | Scheduled Forecasts | Running Forecasts | Synchronisation Status | Synchronisation Monitor | Import Status

Log level	Log creation time	Event Code	Log Message	taskRunId
WARN	09-07-2008 08:21:15	Validation.SoftLimit	SoftLimit min violated for Discharge (Q.m) at Rockenau-SKA, value 0.0 b...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Trier and can not be conve...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Wurzburg and can not be c...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Raunheim and can not be c...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Koeln and can not be conv...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Bonn and can not be conve...	NLRMMC00:000140...
WARN	09-07-2008 08:21:15	Validation.SoftLimit	SoftLimit min violated for Discharge (Q.m) at Cochem, value 22.499966 b...	NLRMMC00:000140...
WARN	09-07-2008 08:21:13	Validation.HardLimit	HardLimit min violated for Water level (H.m) at Raunheim, value 0.969999...	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 08:02:42	ErrorModel.InvalidData	All observed values missing for paramter,location(s): Discharge (Q.m) (Q....	NLRMMC00:000140...
WARN	09-07-2008 07:51:18	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Koeln and can not be conv...	NLRMMC00:000140...
WARN	09-07-2008 07:51:18	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Trier and can not be conve...	NLRMMC00:000140...
WARN	09-07-2008 07:51:18	HydroMeteoTransformation.QHRATI...	Value(s) exceed limits of rating curve/table at Bonn and can not be conve...	NLRMMC00:000140...

Log creation time

End time: 09-07-2008 08:47:15

View period: day 2

Refresh periodically ☑

Log level: WARN

External event code

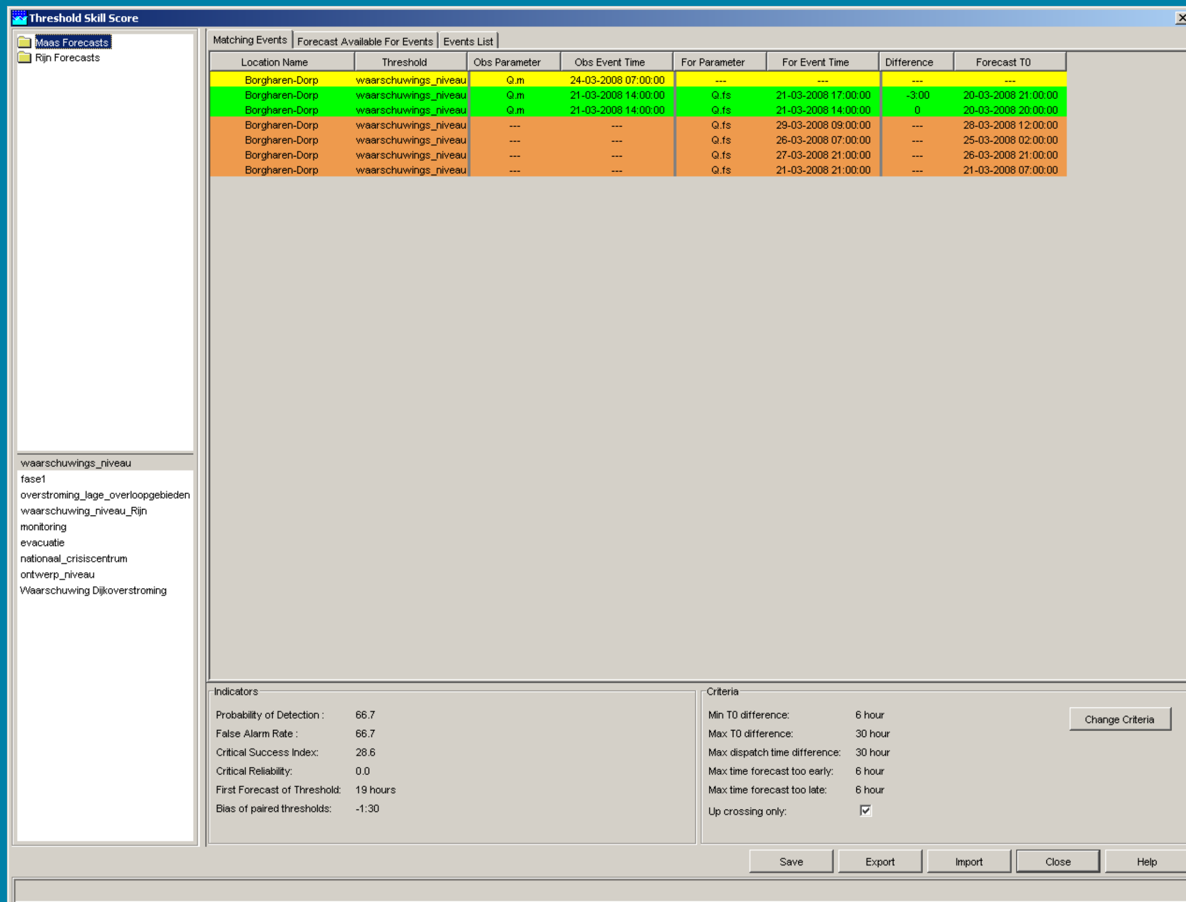
Token in message

Max.number of messages displayed: 250

Refresh | Acknowledge | Save

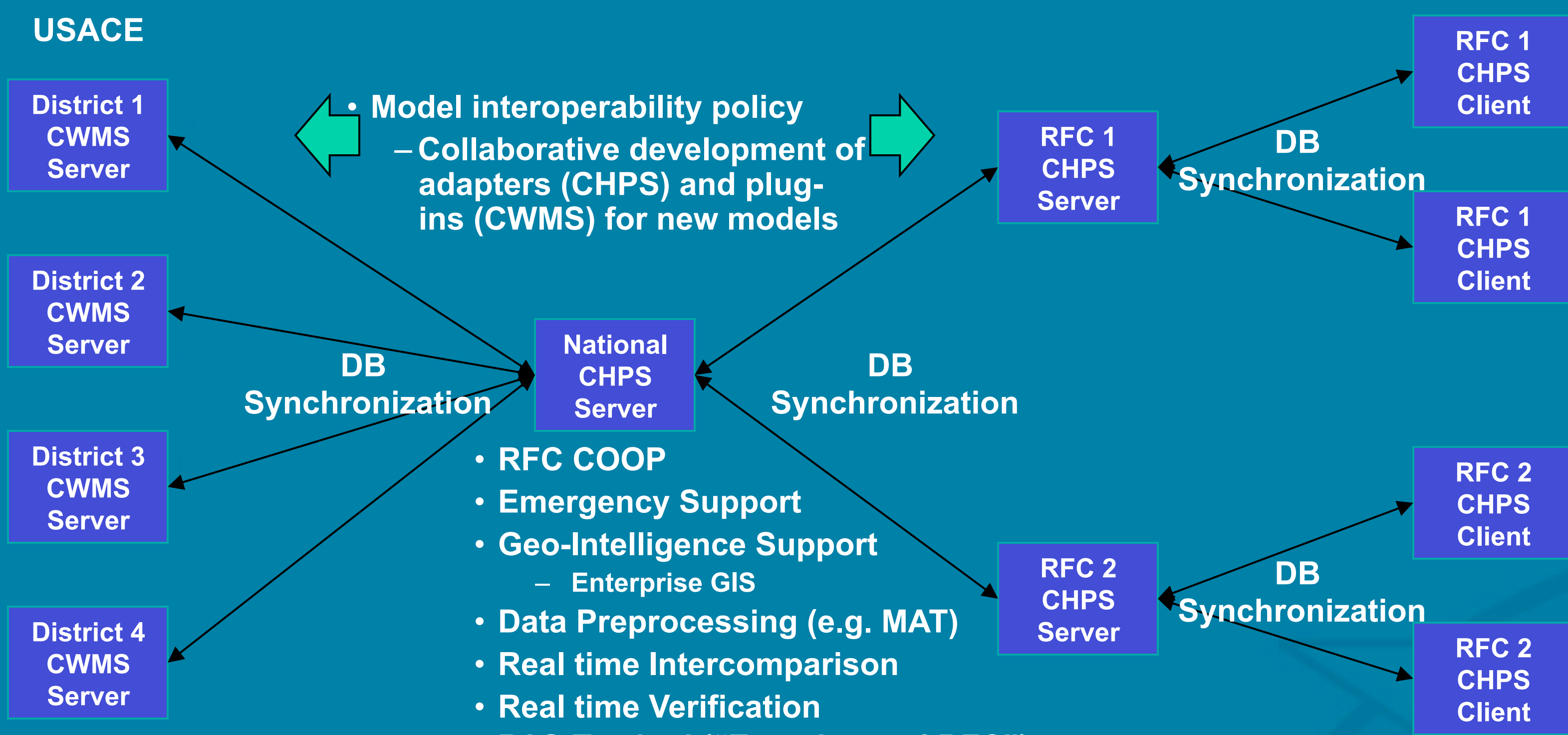
Close | Help

Skill Scores Display



Location Name	Threshold	Obs Parameter	Obs Event Time	For Parameter	For Event Time	Difference	Forecast T0
Borgharen-Dorp	waarschuwings_niveau	Q.m	24-03-2008 07:00:00	---	---	---	---
Borgharen-Dorp	waarschuwings_niveau	Q.m	21-03-2008 14:00:00	Q.fs	21-03-2008 17:00:00	-3:00	20-03-2008 21:00:00
Borgharen-Dorp	waarschuwings_niveau	Q.m	21-03-2008 14:00:00	Q.fs	21-03-2008 14:00:00	0	20-03-2008 20:00:00
Borgharen-Dorp	waarschuwings_niveau	---	---	Q.fs	29-03-2008 09:00:00	---	28-03-2008 12:00:00
Borgharen-Dorp	waarschuwings_niveau	---	---	Q.fs	26-03-2008 07:00:00	---	25-03-2008 02:00:00
Borgharen-Dorp	waarschuwings_niveau	---	---	Q.fs	27-03-2008 21:00:00	---	26-03-2008 21:00:00
Borgharen-Dorp	waarschuwings_niveau	---	---	Q.fs	21-03-2008 21:00:00	---	21-03-2008 07:00:00

Potential CHPS in Joint IWRSS (NOAA+USACE)



- Model interoperability policy
  - Collaborative development of adapters (CHPS) and plug-ins (CWMS) for new models

- RFC COOP
- Emergency Support
- Geo-Intelligence Support
  - Enterprise GIS
- Data Preprocessing (e.g. MAT)
- Real time Intercomparison
- Real time Verification
- R2O Testbed (“Experimental RFC”)
- Flash Flood Guidance

- District COOP
- National Interoperability
- Seamless access to USACE/NWS data
- Enhanced Geo-Intelligence Support
- National distribution of USACE WR information (now mandated)

Questions?

Water Predictions
for
Life Decisions

Thank You

Water Predictions
for
Life Decisions

Backup Slides

National Research Council Reports

- *Assessment of Hydrologic and Hydrometeorological Operations and Services, (1996)*
  - Recommends that the NWS develop a formal, long-term plan for hydrologic science research, which is part of an ongoing dialogue between NWS headquarters and its field offices as to the most appropriate research and product development for hydrologic services.
- *Toward a new Advanced Hydrologic Prediction Service (AHPS)* (2006)
  - AHPS developers are encouraged to work closely with satellite precipitation groups to ensure that AHPS hydrologic requirements for precipitation are considered in other federal activities, such as the National Aeronautics and Space Administration's Global Precipitation Measurement mission.
  - The NWS should strengthen quantitative precipitation estimation (QPE) and quantitative precipitation forecasts (QPF) for hydrologic prediction through an end-to-end evaluation that assesses QPE/QPF quality and impacts on flood and streamflow products for basins of diverse size and topography.
  - The NWS should strengthen connections between DMIP Phase I/DMIP Phase II and AHPS goals.
  - The NWS should clarify the criteria and decision–making process for selecting the next generation of hydrologic model(s) for AHPS, using an advisory group that involves modeling experts from inside and outside of the NWS to ensure that the state-of-the-art modeling advances are incorporated objectively into NWSRFS.
  - The NWS should invest in the next generation of NWSRFS that includes a flexible framework that allows alternative models, methods, or features that can be tested, verified, and implemented expediently. A total redesign of the NWSRFS is needed for AHPS to fulfill its scientific and technical goals.

National Research Council Reports

- *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts. (2006)*
  - OHD should implement operational hydrology databases that span a large range of scales in space and time. The contribution of remotely sensed and onsite data and the associated error measures to the production of such databases should be delineated.
  - OHD should organize workshops with participation from all sectors of the Enterprise to design alternatives to the AHPS ensemble prediction system components and develop plans for intercomparisons through retrospective studies, demonstration with operational data, and validation, and for participation in testbed demonstration experiments.
  - OHD should develop methods for seamlessly blending short-term (weather) with longer-term (climate) ensemble predictions of meteorological forcing within the operational ensemble streamflow prediction system. This will require NCEP model output downscaling and bias adjustment, and real-time data availability.

Outline

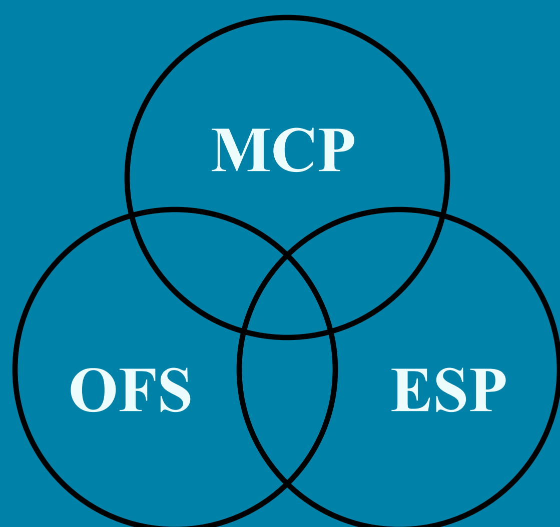
- Background and history
- Why are we doing this?
- What are we doing?
- How are we doing it?
- When will we do it?
- Samples of existing interface displays

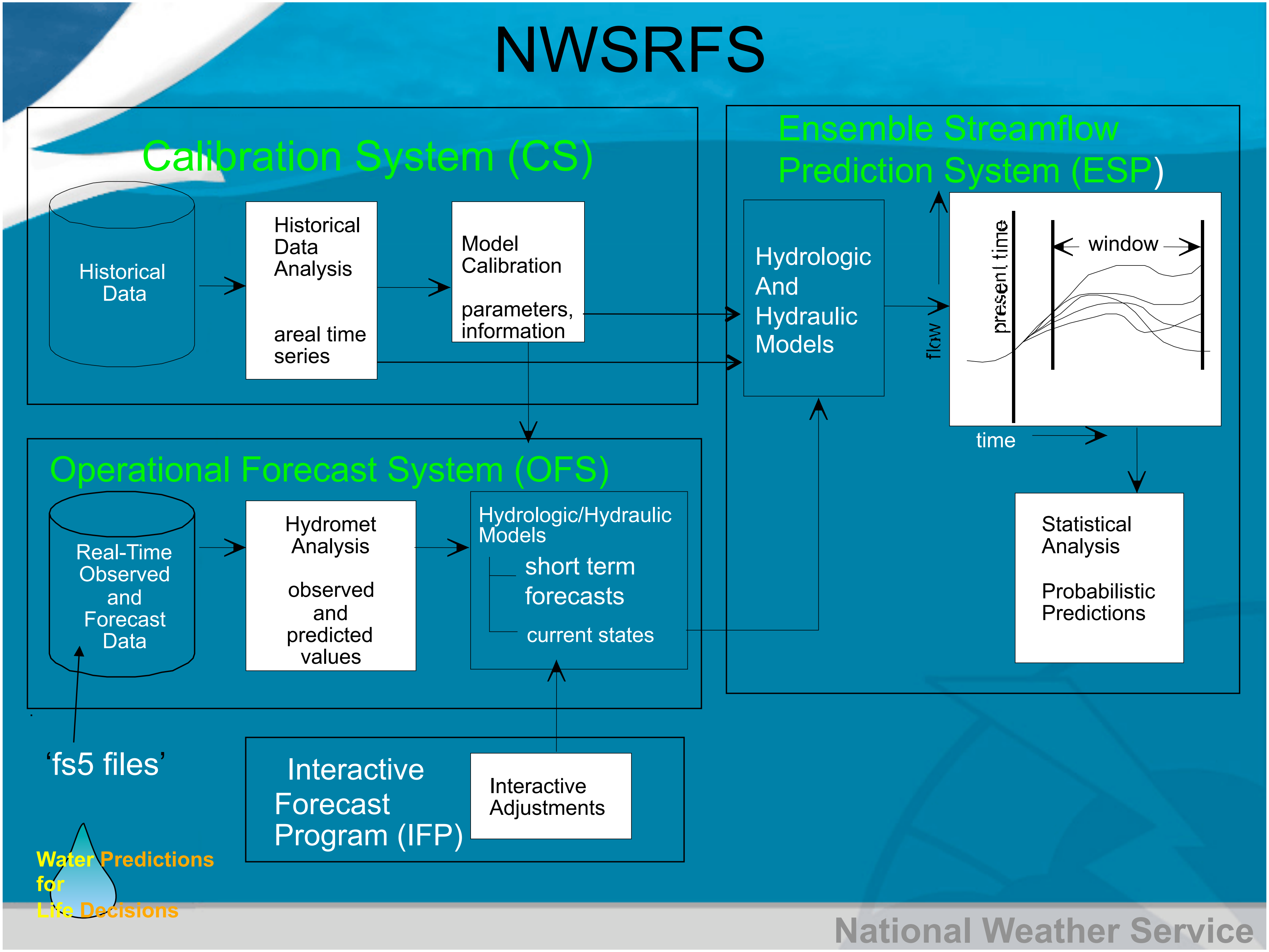
- How can this mesh with USACE efforts?

National Weather Service River Forecast System

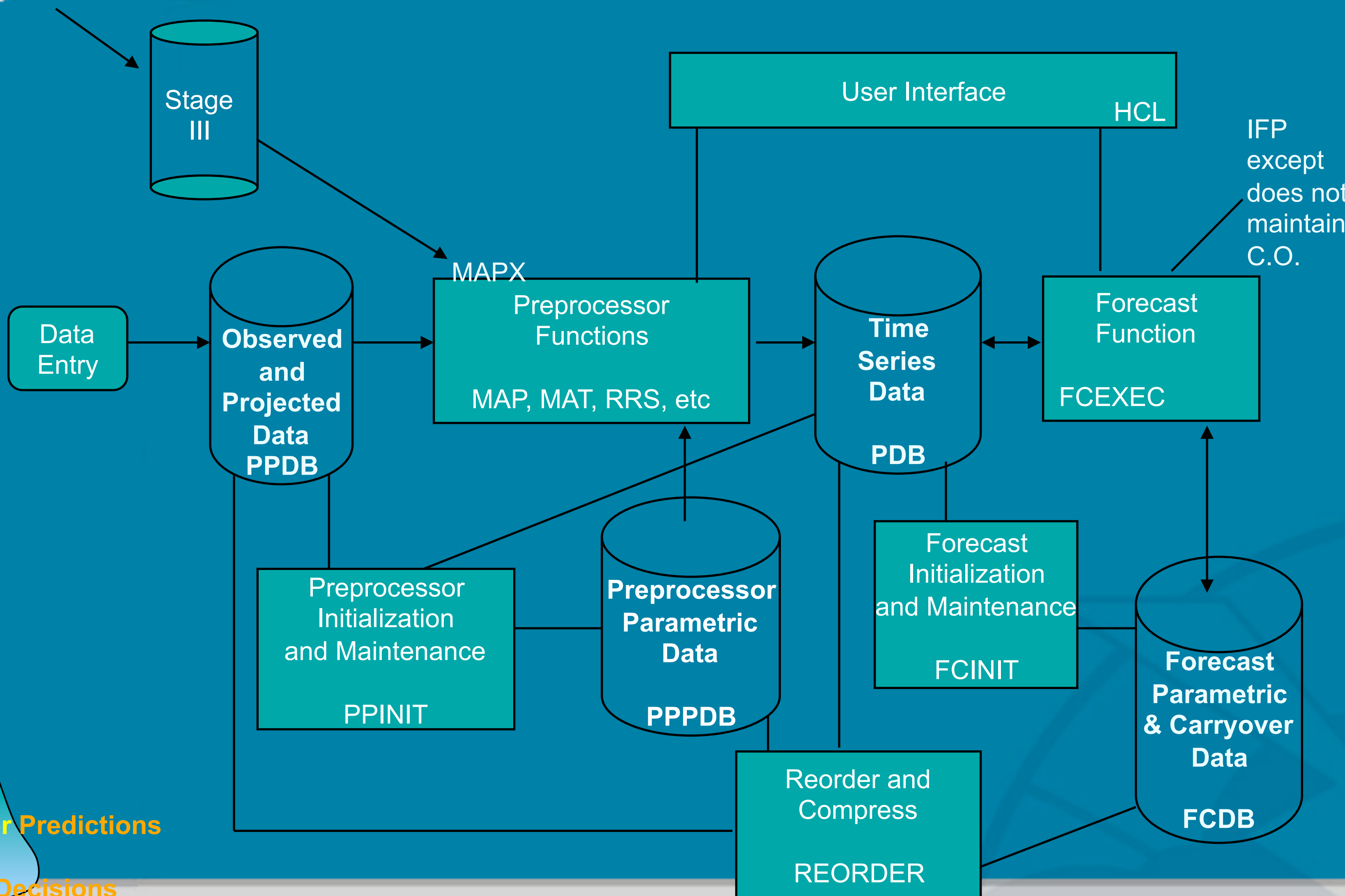
Operates in 3 integrated modes.

- Calibration <== parameter estimation
- Operational <== short term deterministic forecasts
- Ensemble <== longer term forecasts




NWSRFS
Calibration System (CS)
Historical Data
Historical Data Analysis
areal time series
Model Calibration
parameters, information
Ensemble Streamflow Prediction System (ESP)
Hydrologic And Hydraulic Models
present time
window
flow
time
Operational Forecast System (OFS)
Real-Time Observed and Forecast Data
Hydromet Analysis
observed and predicted values
Hydrologic/Hydraulic Models
short term forecasts
current states
Statistical Analysis
Probabilistic Predictions
'fs5 files'
Interactive Forecast Program (IFP)
Interactive Adjustments
Water Predictions for Life Decisions
National Weather Service

NWSRFS - OFS



Stage III
MAPX
User Interface
HCL
IFP except does not maintain C.O.
Data Entry
Observed and Projected Data PPDB
Preprocessor Functions
MAP, MAT, RRS, etc
Time Series Data
PDB
Forecast Function
FCEXEC
Forecast Initialization and Maintenance
FCINIT
Preprocessor Initialization and Maintenance
PPINIT
Preprocessor Parametric Data
PPPDB
Forecast Parametric & Carryover Data
FCDB
Reorder and Compress
REORDER

Development Time Line

George Smith (NWS/OH) presented the IHFS (precursor to CHPS) at the April '96 DOH Workshop

OHD initiated exploration in '03

- Infrastructure analysis
- Several candidates considered including Delft-FEWS in Oct '05

CAT (CHPS Acceleration Team) formed at NHIC meeting in Jan '06 to accelerate pursuit of CHPS

- AB, NC, NW volunteered to work w/ OHD. CN later drafted.
- Criteria established through evaluation of NWSRFS strengths and weaknesses (Apex facilitation, available from HSEB)
- Evaluate Delft-FEWS as a CHPS candidate

Delft-FEWS Prototype Evaluation

Initiated Oct '06

- Facilitated by OHD, Apex, RTi, and WL-Delft Hydraulics
- NWRFC and NCRFC implementation
  - Strategy to include basic functionality (including SAC_SMA) but use surrogate FEWS models/functions/displays
- Apr '07 (NWRFC) workshop to review results
  - "Very promising", but more evaluation needed…
    - » MODS-like capability
    - » Client-Server application
    - » Integration of SNOW-17
    - » Displays with English Units

FEWS Prototype Evaluation

Follow-on work to address Apr '07 concerns

- NW, NC, and AB RFCs. CN for ResSim project.
- Dec '07 (NCRFC) workshop to review results
  - Solid progress on MODs capability
  - Client-Server demonstrated
  - SNOW-17 integration easier than expected
  - Display units mostly taken care of
  - ESP capabilities demonstrated and discussed
  - Followed by training on FEWS configuration

FEWS is currently running and identically configured at AB, CN, NC, and NW RFCs.

CAT Recommendation
Approved by Gary Carter – January 17,

Proceed with implementation of Delft-FEWS as the CHPS software infrastructure.

Target operational use at all RFCs within 3 years.

Resource implications

- Major OHD focus
- Terminate “dead-end” NWSRFS enhancements
- Align/re-evaluate HSMB-oriented “Research to Operations” (RTO) projects

Retain CAT with a revised implementation charter

Implementation Strategy

Port models that require calibration

- BASEFLOW, SARROUTE, CONS_USE, LAG/K, LAY-COEF, TATUM,
- TIDEREV, MUSKROUT, RES-J, RSNWELEV, SNOW-17, CHANLOSS,
- STAGE-Q, SSARRESV, STAGEREV, UNIT-HG, RES-SNGL, SAC-SMA

Create adapters for several new models (e.g. HEC-RAS)

Rely existing data and display utilities with identified enhancements

- CLEAR-TS, CHANGE-T, ADD/SUB, SET-TS, MULT/DIV, NOMSNG, MERG-TS,
- MEAN-Q, WEIGHT-TS, LOOKUP3, LOOKUP, DELTA-TS, ADJUST-Q,
- ADJUST-H, ADJUST-T, PLOT-TS, PLOT-TUL

Implementation Strategy

Provide for forecaster run-time modifications

- IGNORETS, FMAP, SSARREG, MFC, RRICHNG, SWITCHTS, TSCHNG,
- CHGBLEND, WECHNG, RAINSNOW, RRIMULT, WEADD, TSADD, SACCO,
- AESCHNG, ROMULT, SETMSNG, UADJ, ROCHNG, UHGCHNG, SETQMEAN,
- UHGDATE, QCSHIFT, QPSHIFT, HECRAS

Provide for existing level of ensemble operations, products, and services

- Port ESPADP to use FEWS architecture and data resources