DEMONSTRATING INTEGRATED FORECAST AND RESERVOIR MANAGEMENT (INFORM) FOR NORTHERN CALIFORNIA IN AN OPERATIONAL ENVIRONMENT

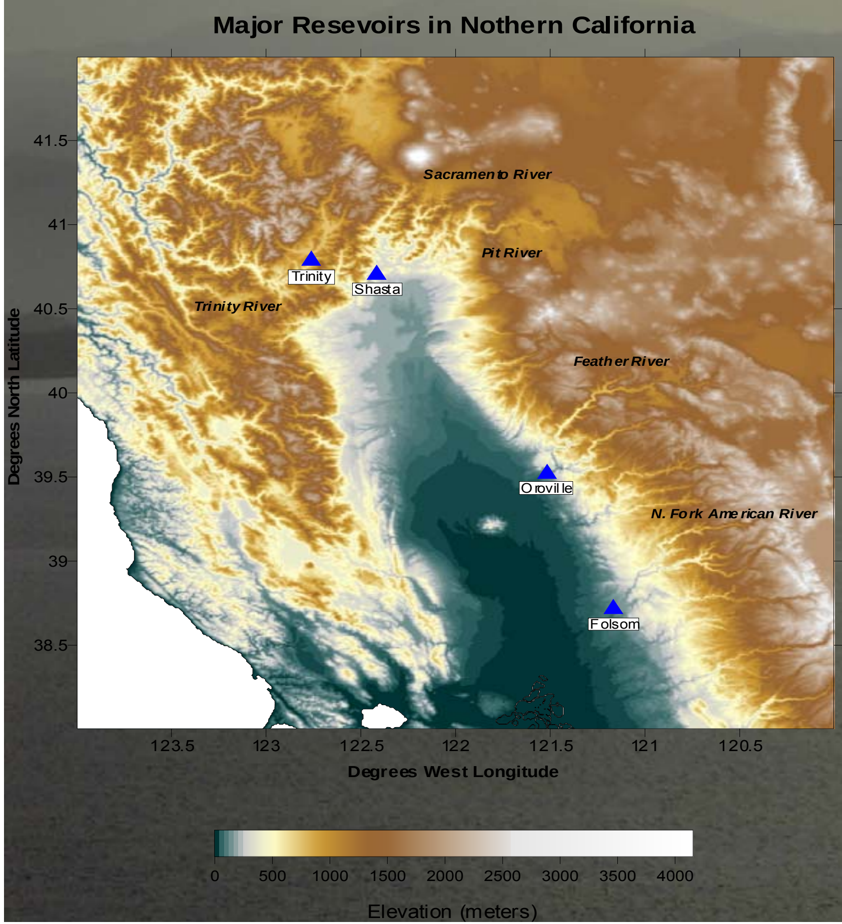
Konstantine P. Georgakakos and Nicholas E. Graham
HYDROLOGIC RESEARCH CENTER
(http://www.hrc-lab.org)

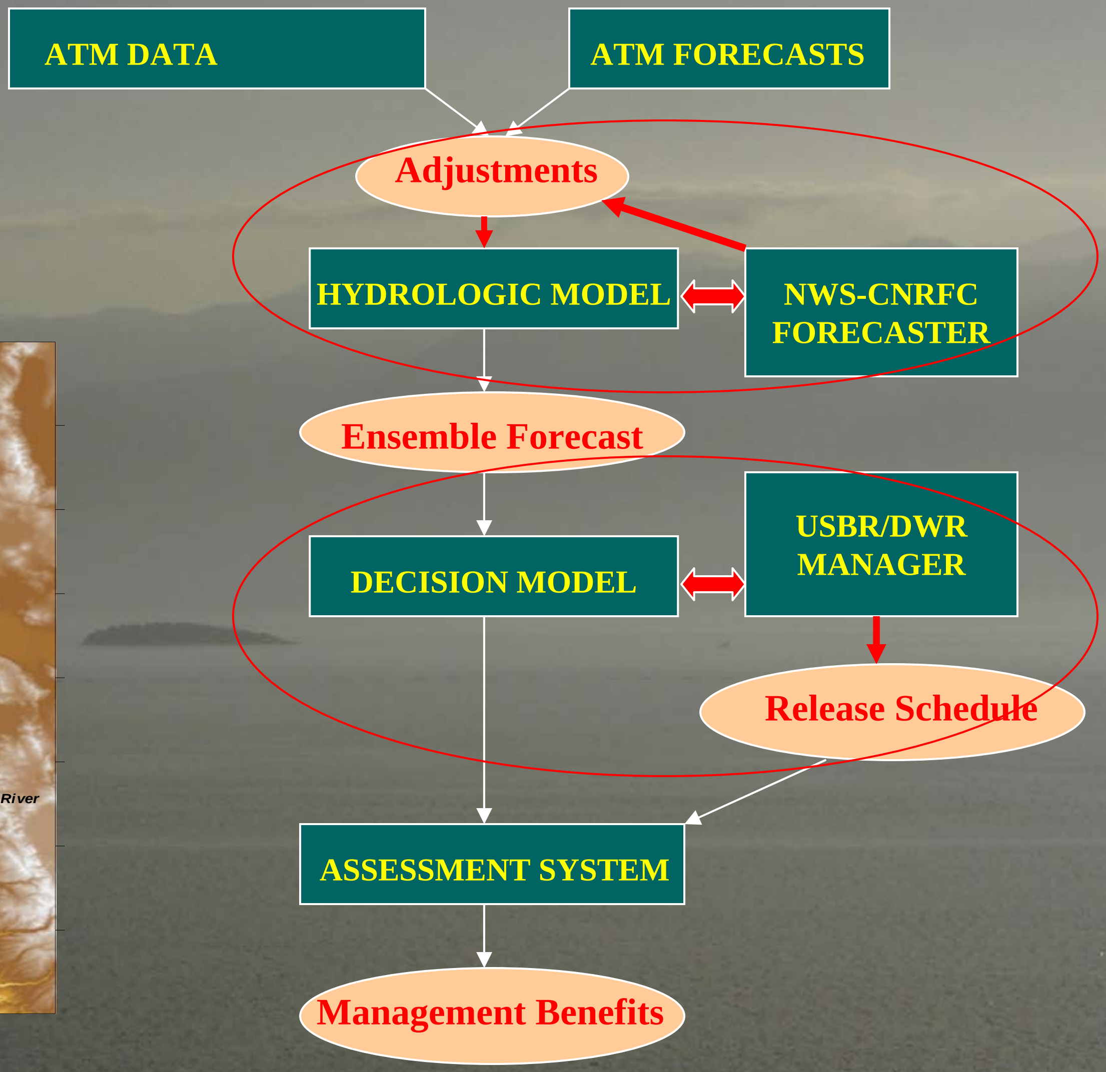
Aris P. Georgakakos and Huaming Yao
GEORGIA WATER RESEARCH INSTITUTE

INTEGRATED FORECAST AND RESERVOIR MANAGEMENT – INFORM A DEMONSTRATION PROJECT

- *Vision:* Increase efficiency of water use in Northern California using climate, hydrologic and decision science
- *Goal :* Demonstrate the value of climate-hydrology forecasting for multi-objective reservoir management
- *Means:* Implement integrated forecast-management systems for the Northern California reservoirs and perform tests with actual data and management input.
- *Lead Organizations:* Hydrologic Research Center, San Diego, CA and Georgia Water Resources Research Institute, Atlanta, GA
- *Funding:* NOAA OGP, California Energy Commission, CALFED (2003 – 2007)

INTEGRATED SYSTEM DIAGRAM





ATM DATA

ATM FORECASTS

Adjustments

HYDROLOGIC MODEL

NWS-CNRFC FORECASTER

Ensemble Forecast

DECISION MODEL

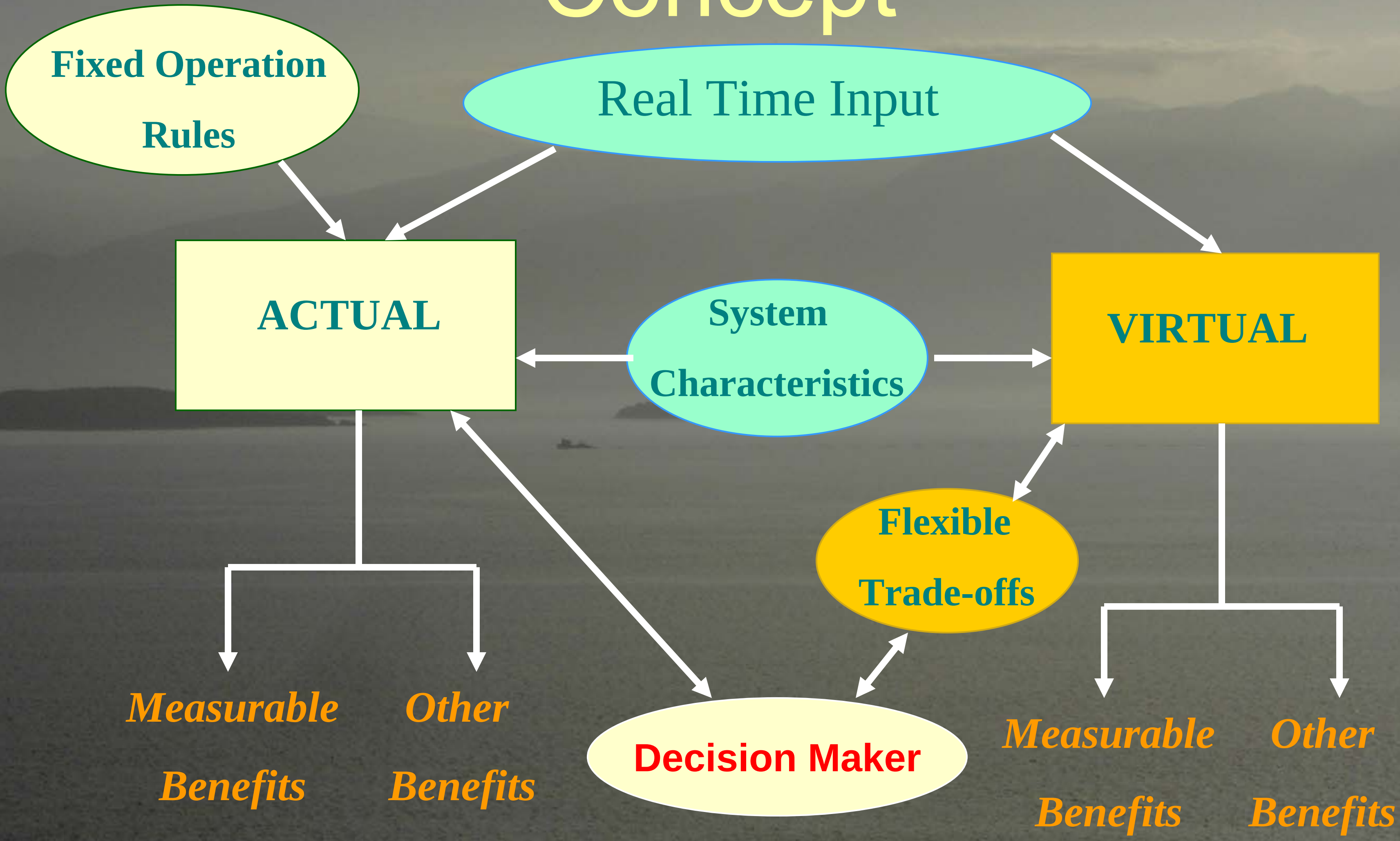
USBR/DWR MANAGER

Release Schedule

ASSESSMENT SYSTEM

Management Benefits

Demonstration Concept



Fixed Operation Rules

Real Time Input

ACTUAL

System Characteristics

VIRTUAL

Flexible Trade-offs

Measurable Benefits

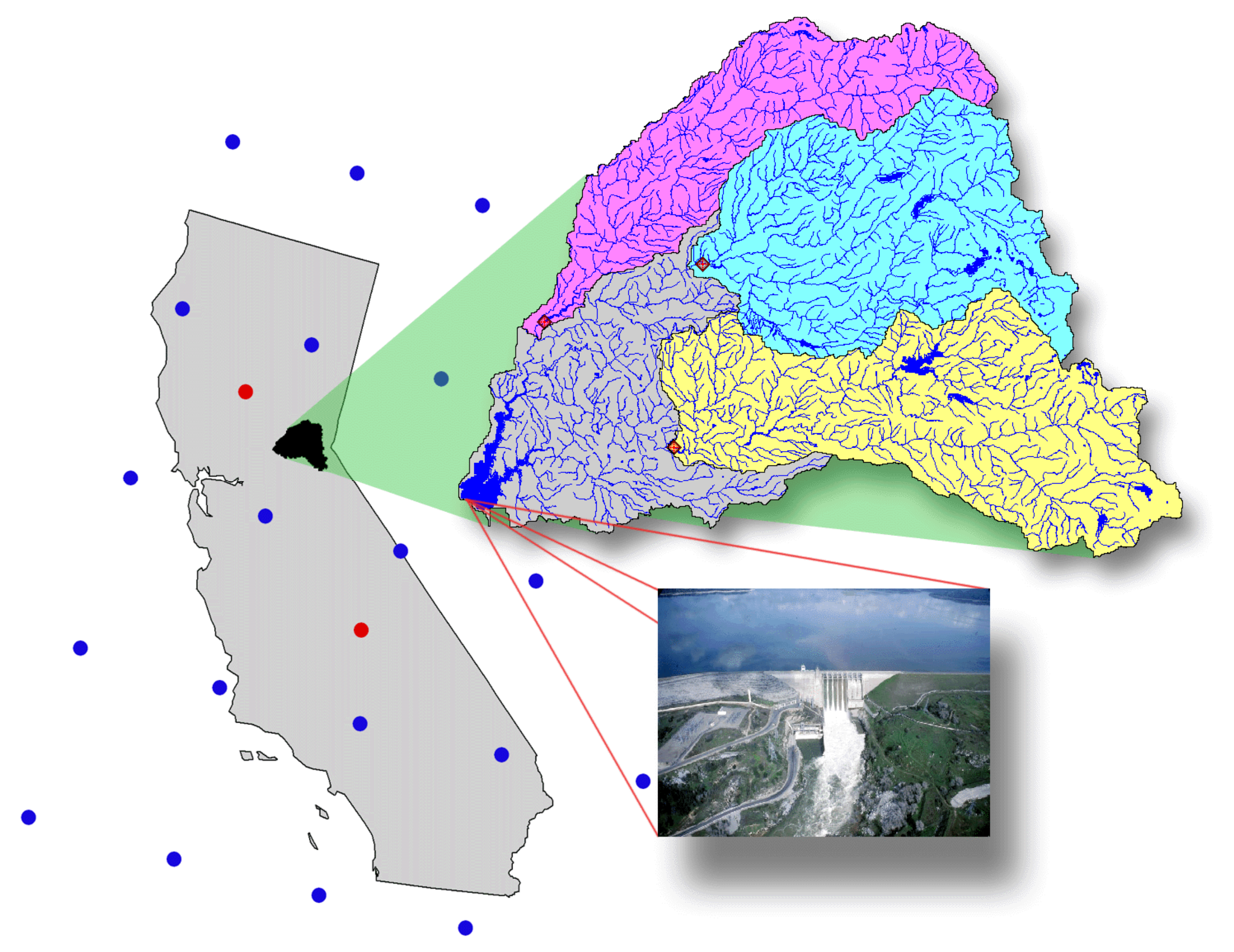
Other Benefits

Decision Maker

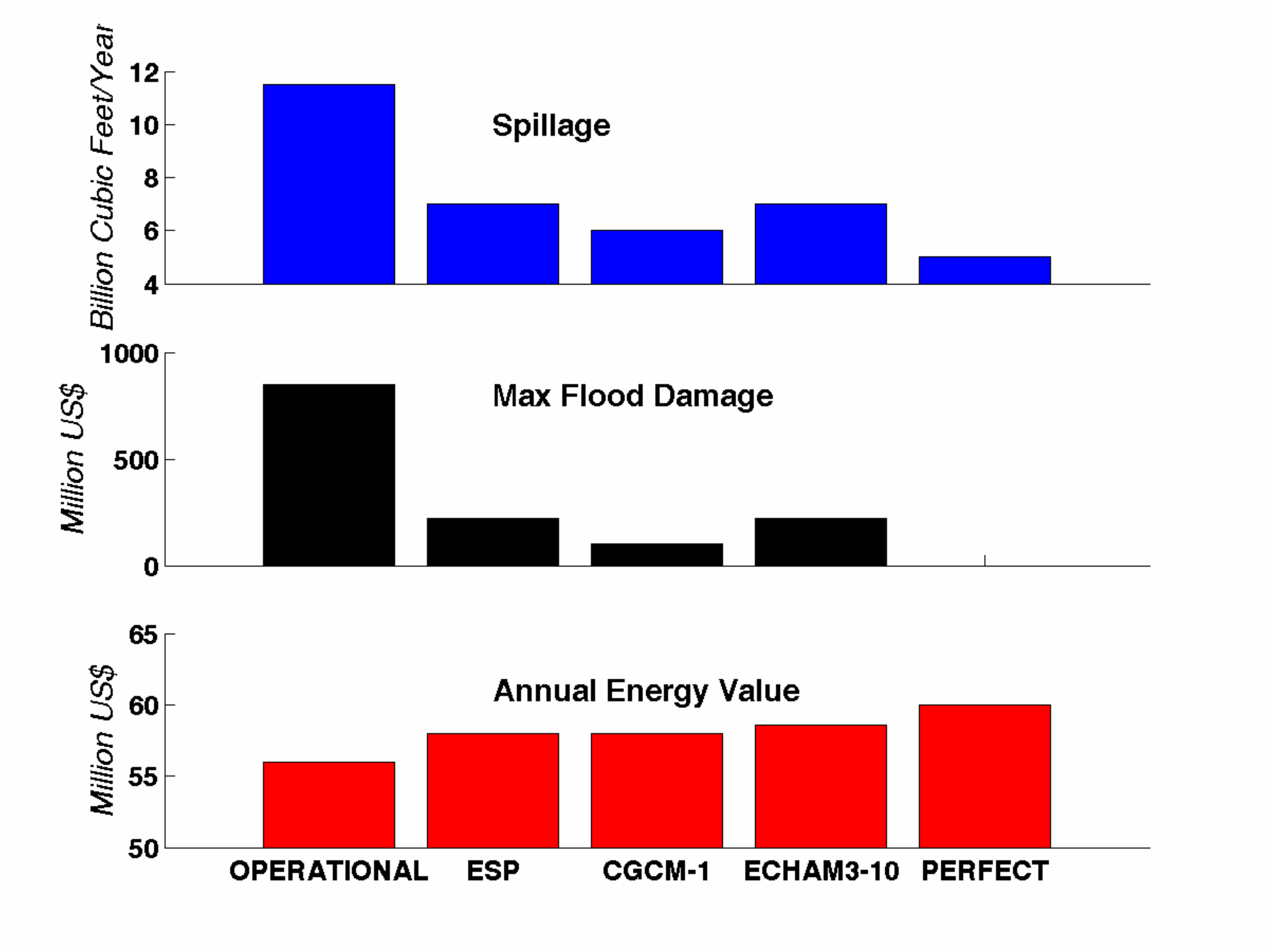
Measurable Benefits

Other Benefits

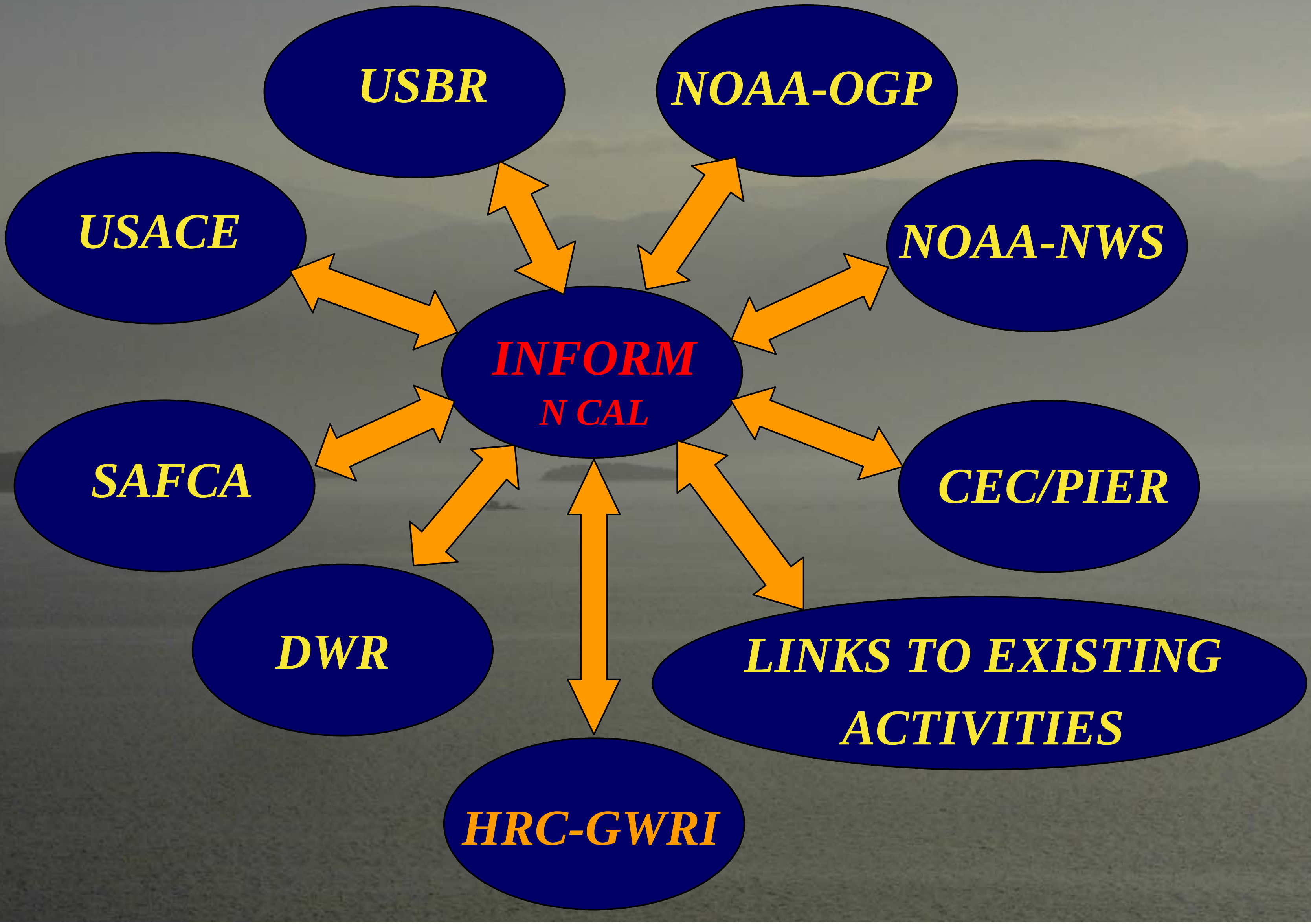
Feasibility Results for Folsom Lake



Feasibility Results for Folsom Lake



COOPERATION



INFORM
N CAL

USBR

NOAA-OGP

NOAA-NWS

CEC/PIER

LINKS TO EXISTING ACTIVITIES

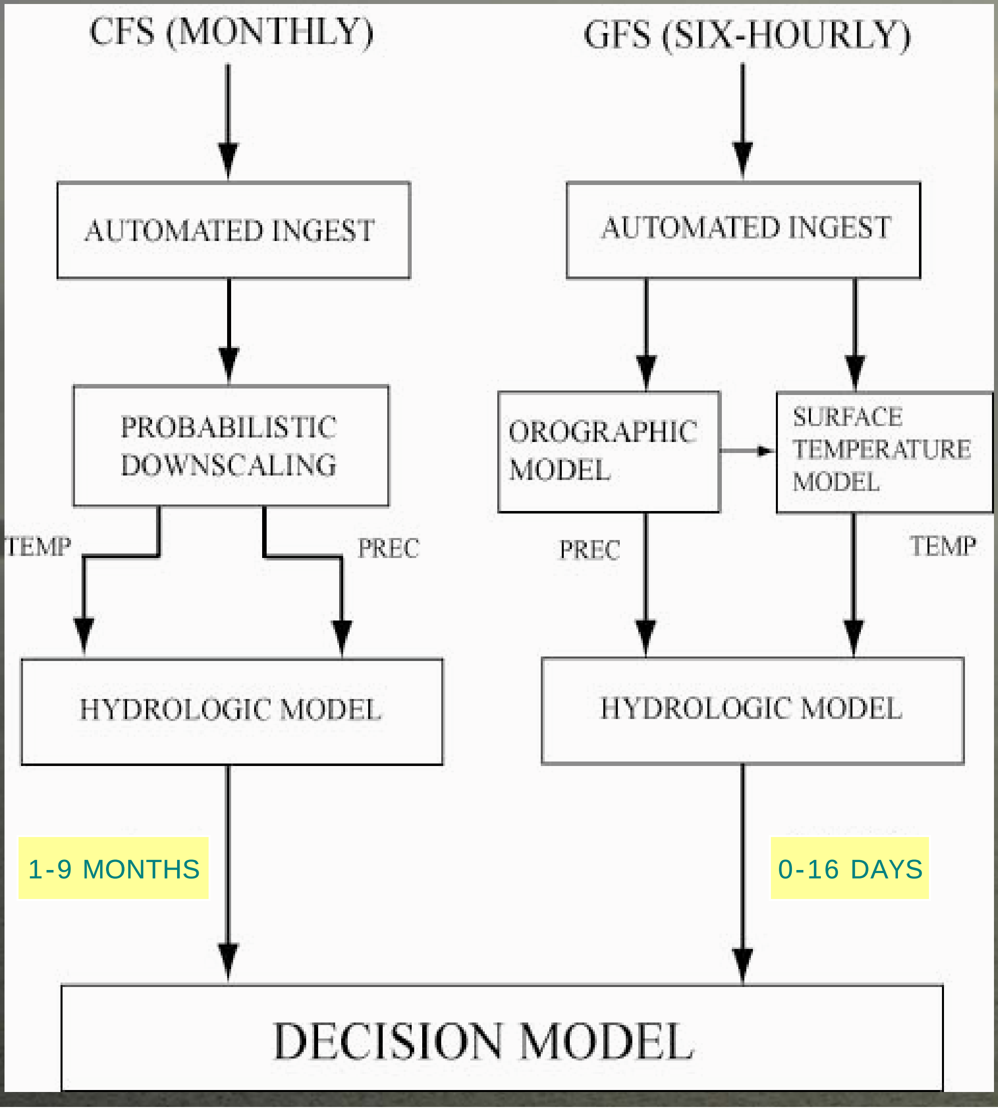
HRC-GWRI

DWR

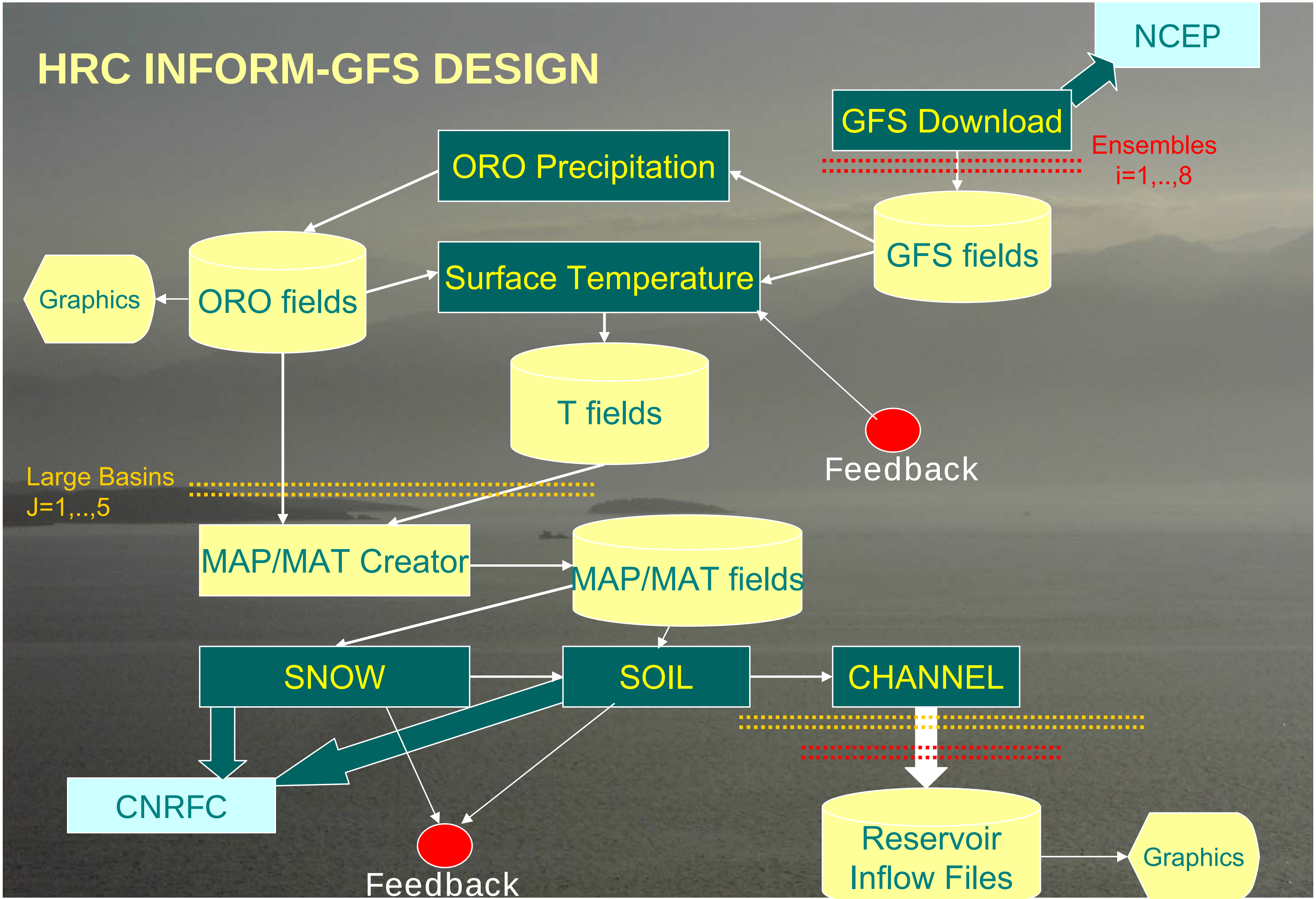
SAFCA

USACE

INFORM System Climate and Weather Data Components and Links



HRC INFORM-GFS DESIGN



NCEP

GFS Download

Ensembles
i=1,..,8

ORO Precipitation

GFS fields

Graphics

ORO fields

Surface Temperature

T fields

Feedback

Large Basins
J=1,..,5

MAP/MAT Creator

MAP/MAT fields

SNOW

SOIL

CHANNEL

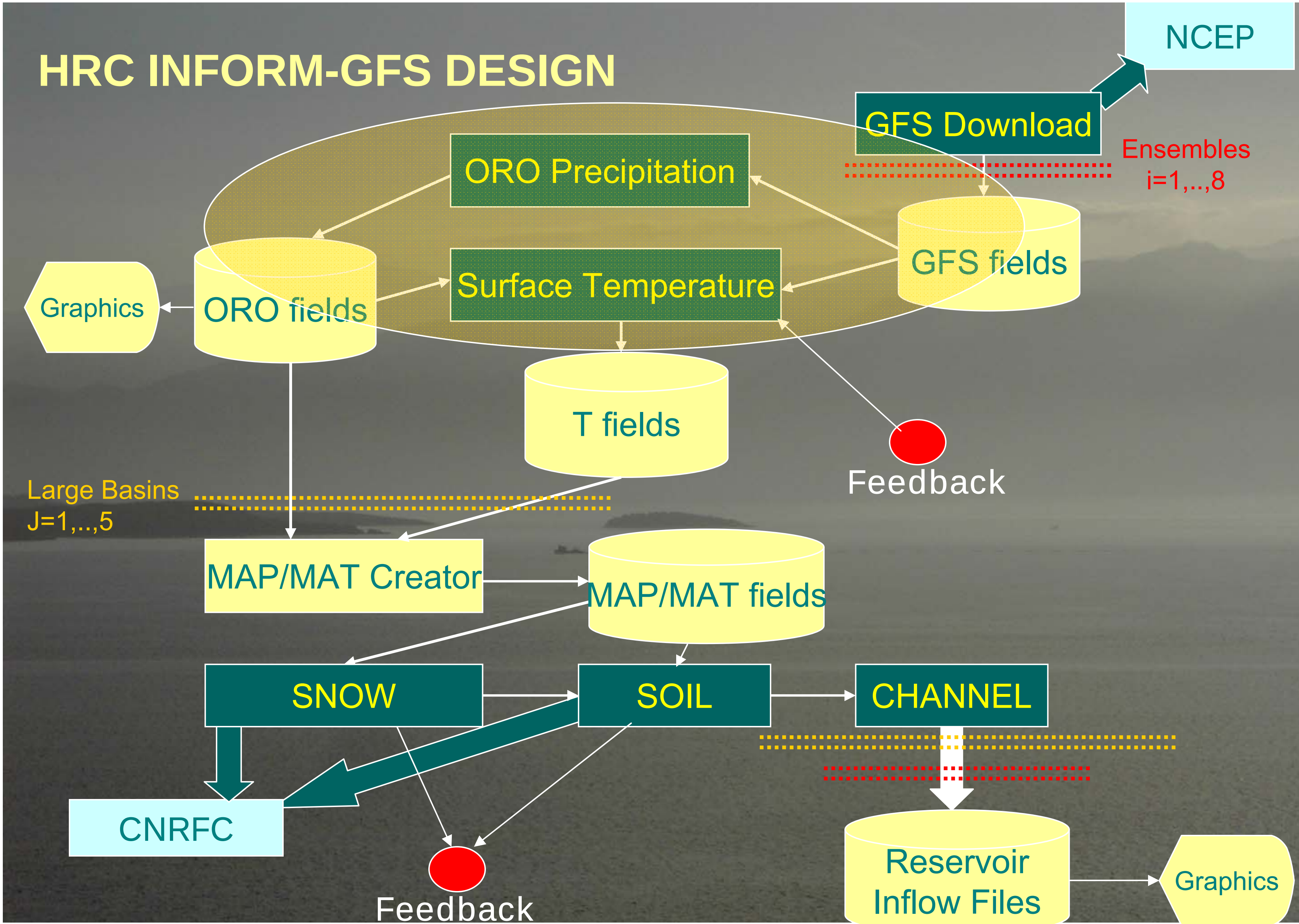
CNRFC

Feedback

Reservoir
Inflow Files

Graphics

HRC INFORM-GFS DESIGN



Simplified Orographic Surface Precipitation Model

Potential Theory Surface Wind

$\nabla \times U = 0$ ⟶ Potential ϕ exists

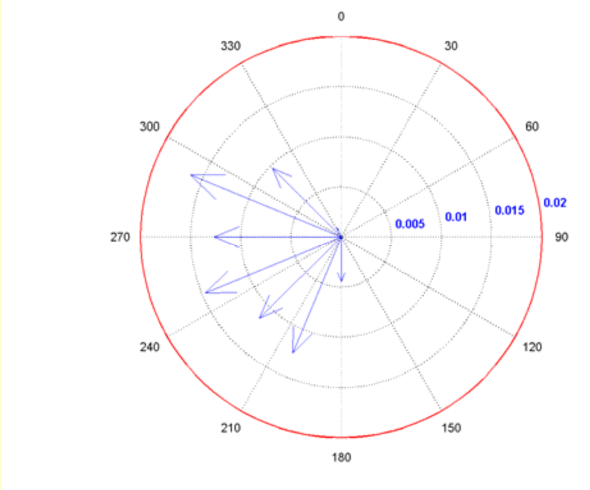
$\nabla \bullet U = 0$ ⟶ Laplace's equation

$$\nabla^2 \phi = 0 \qquad u = \nabla \phi$$

Boundary Conditions:

$\partial\phi/\partial y = u_o\ (y=0, K)$;… $\partial\phi/\partial z = u_o(\partial s/\partial y)\ (z=-H)$

10kmx10km



Folsom Drainage

Water Continuity and Surface Precipitation

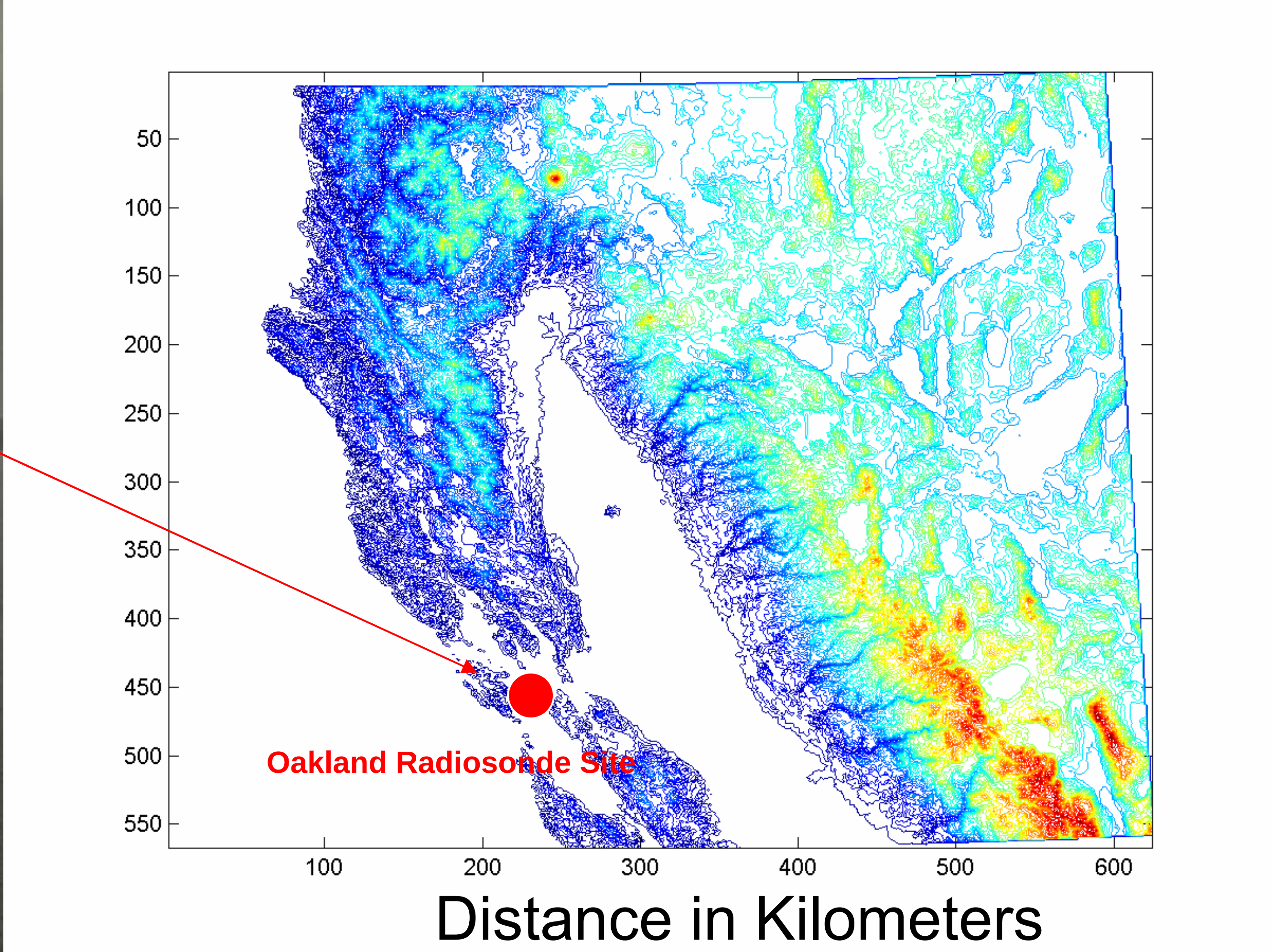
Water Substance Continuity with Microphysics driven by 3-D wind; e.g.,

$$\frac{\partial M}{\partial t} = -v\frac{\partial M}{\partial x} - u\frac{\partial M}{\partial y} - (V+w)\frac{\partial M}{\partial z} - M\frac{\partial V}{\partial z} + Mw\frac{\partial \ln \rho}{\partial z} + k_1(m-a) + k_2 E N_0^{1/8} m M^{7/8} \exp(kz/2) + k_3 N_0^{7/20} m M^{13/20}$$

Downscaling Domain

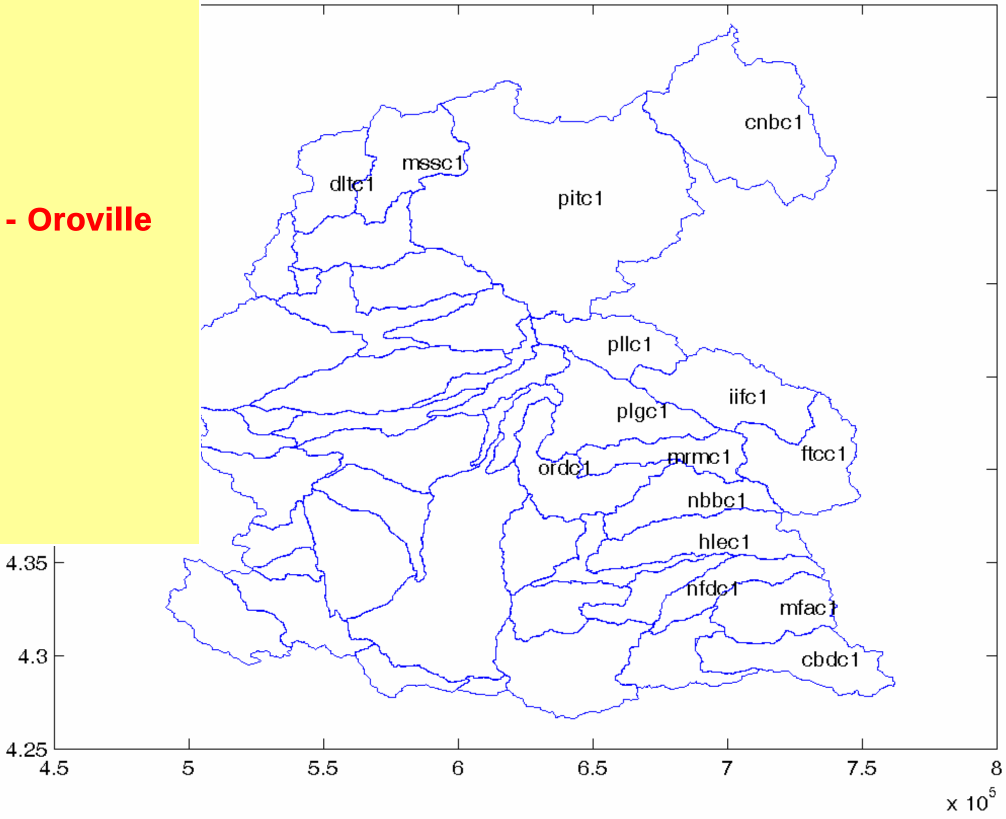
Nov – May
1969 – 2004

NCEP Global
Reanalysis Forcing
$2.5^o x 2.5^o$



Precipitation Downscaling – Regional Validation

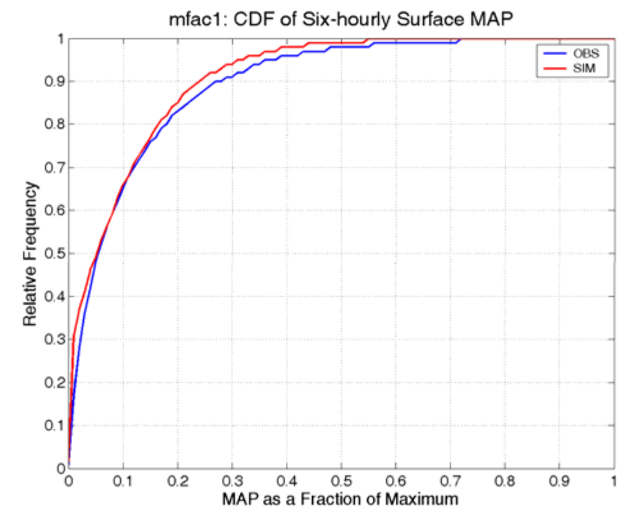
cbdc1: South Fork, American River - Folsom
cnbc1: Pit River at Canby - Shasta
dltc1: Sacramento River at Delta - Shasta
ftcc1: Middle Fork feather at Clio - Oroville
hlec1: South Yuba River
iifc1: Indian Creek - Oroville
mfac1: Middle Fork, American River - Folsom
mrmc1: Middle Fork Feather River at Merrimac - Oroville
mssc1: McCloud River - Shasta
nbbc1: North Yuba River
nfdc1: North Fork, American River - Folsom
ordc1: Local Feather River at Oroville - Oroville
pitc1: Pit River at Montgomery Creek - Shasta
plgc1: North Fork Feather River - Oroville
pllc1: Lake Almanor drainage - Oroville

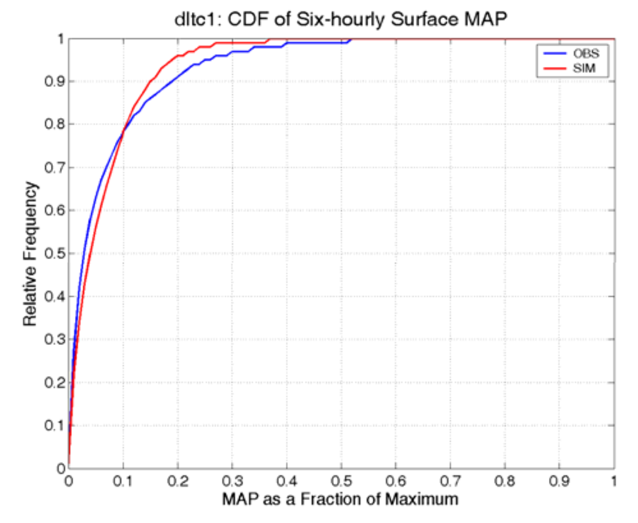


Precipitation Downscaling – Performance

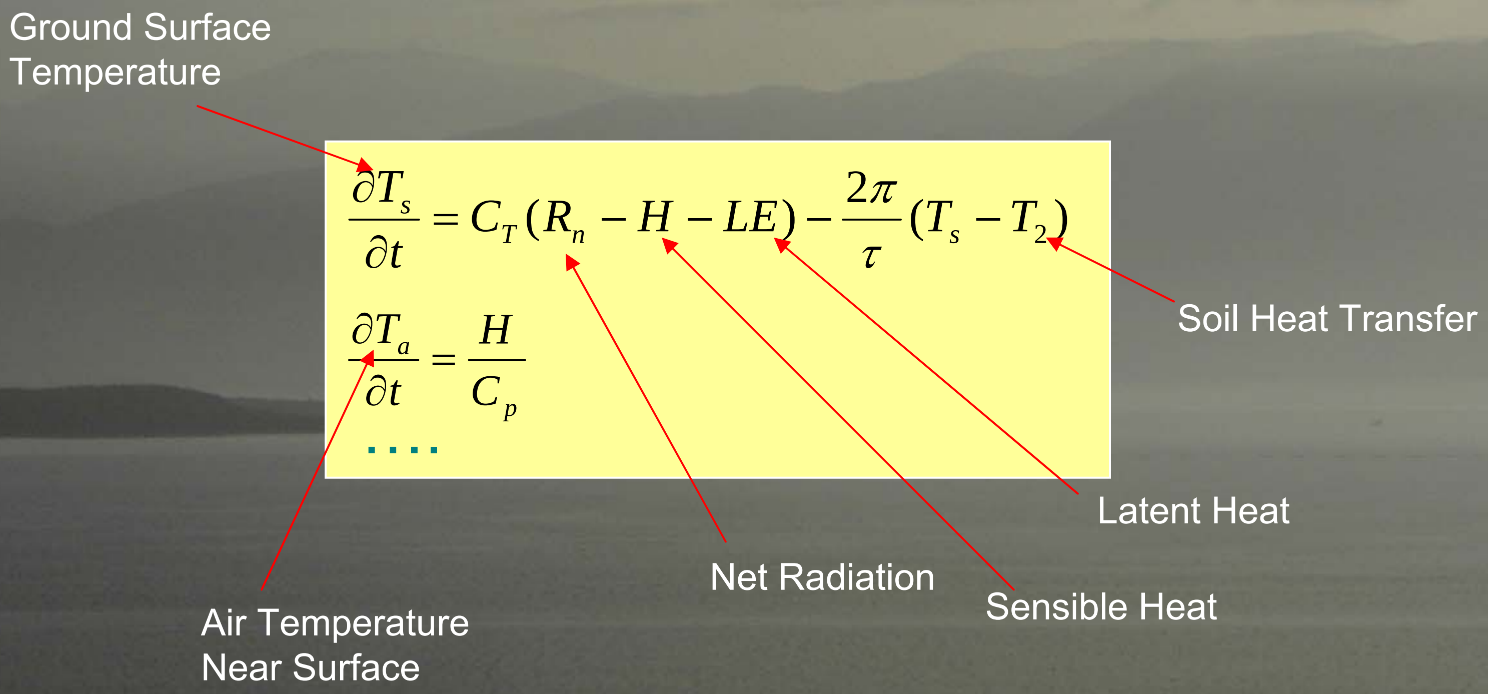
Southwesterly 700mbar Wind & SimPrec > 1 mm/6hrs

BASIN	*AV-OBS*	*STD-OBS*	*AV-SIM*	*STD-SIM*	*CC-S/O*
cbdc1	2.70	6.36	5.86	7.87	0.66
cnbc1	0.59	1.24	1.84	1.72	0.36
dltc1	3.94	1.85	7.25	3.11	0.38
ftcc1	1.53	0.90	3.97	1.61	0.59
hlec1	3.58	4.39	7.16	5.58	0.69
iifc1	1.85	1.10	4.12	2.24	0.48
mfac1	3.22	6.46	6.71	8.27	0.68
mrmc1	3.64	3.87	7.15	5.10	0.62
mssc1	4.05	1.74	7.56	2.97	0.40
nbbc1	4.11	4.35	8.08	5.61	0.66
nfdc1	3.09	4.55	6.43	5.92	0.67
ordc1	4.34	3.58	8.49	4.92	0.53
pitc1	1.56	1.15	3.30	1.53	0.48
plgc1	3.40	2.75	6.80	3.90	0.54
pllc1	2.43	2.32	5.13	3.15	0.56





Temperature Downscaling - Model



Ground Surface Temperature

$$\frac{\partial T_s}{\partial t} = C_T(R_n - H - LE) - \frac{2\pi}{\tau}(T_s - T_2)$$

$$\frac{\partial T_a}{\partial t} = \frac{H}{C_p}$$

....

Soil Heat Transfer

Latent Heat

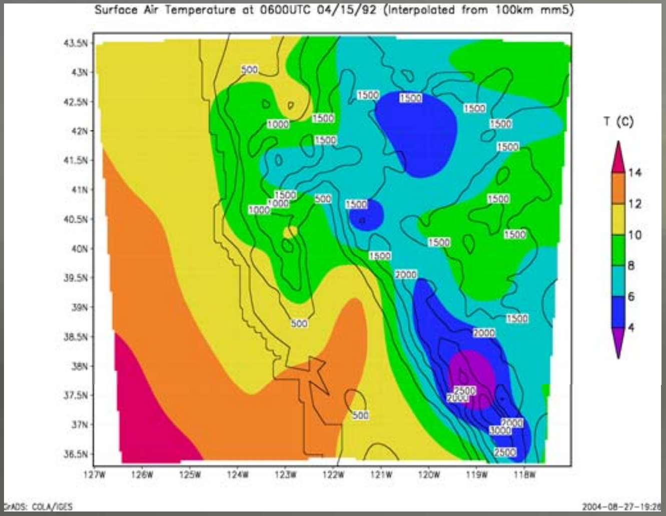
Net Radiation

Sensible Heat

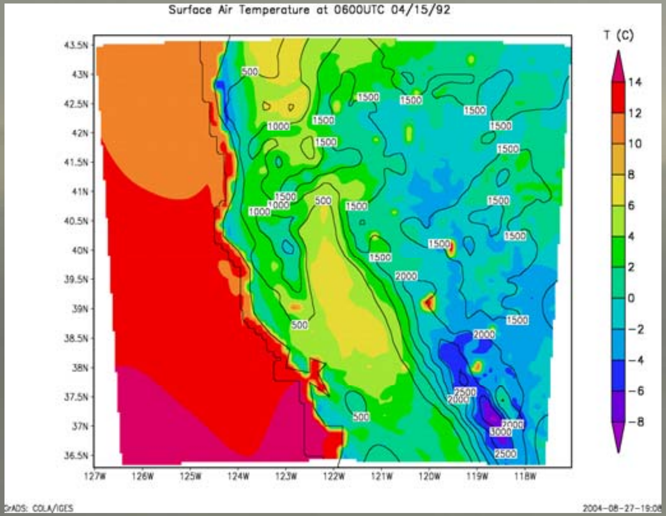
Air Temperature Near Surface

$$H = \rho_a C_p C_{dh} V_a (T_s - T_a)$$

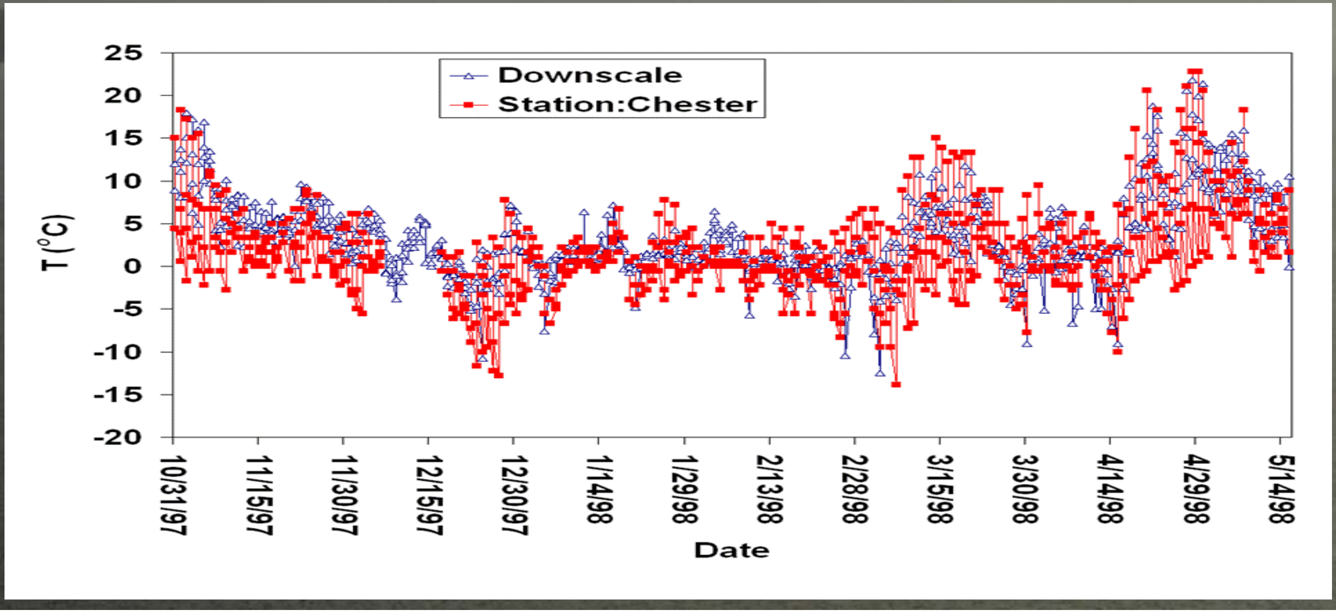
Temperature Downscaling - Tests

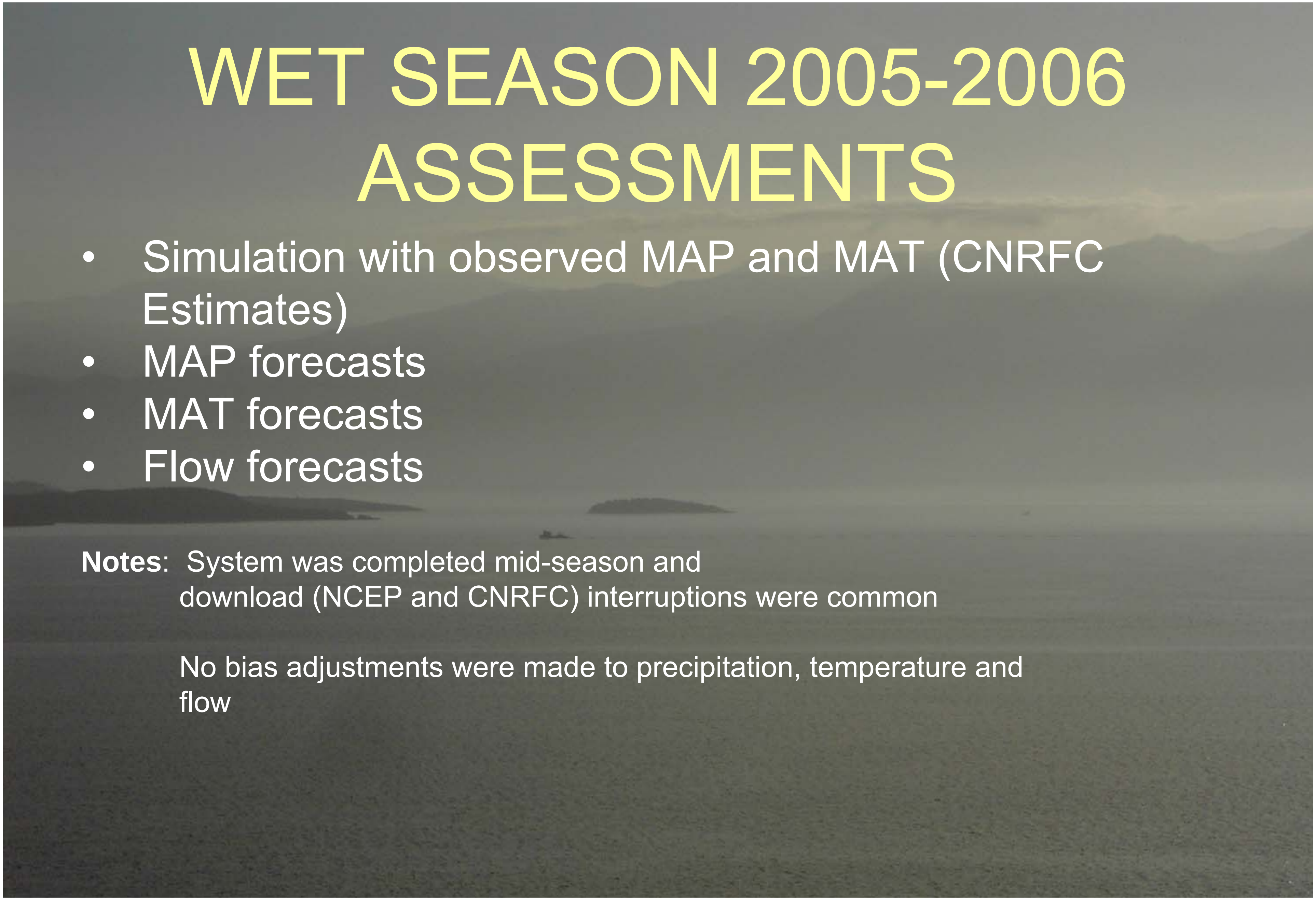


Surface Air Temperature at 0600UTC 04/15/92 (Interpolated from 100km mm5)



Surface Air Temperature at 0600UTC 04/15/92





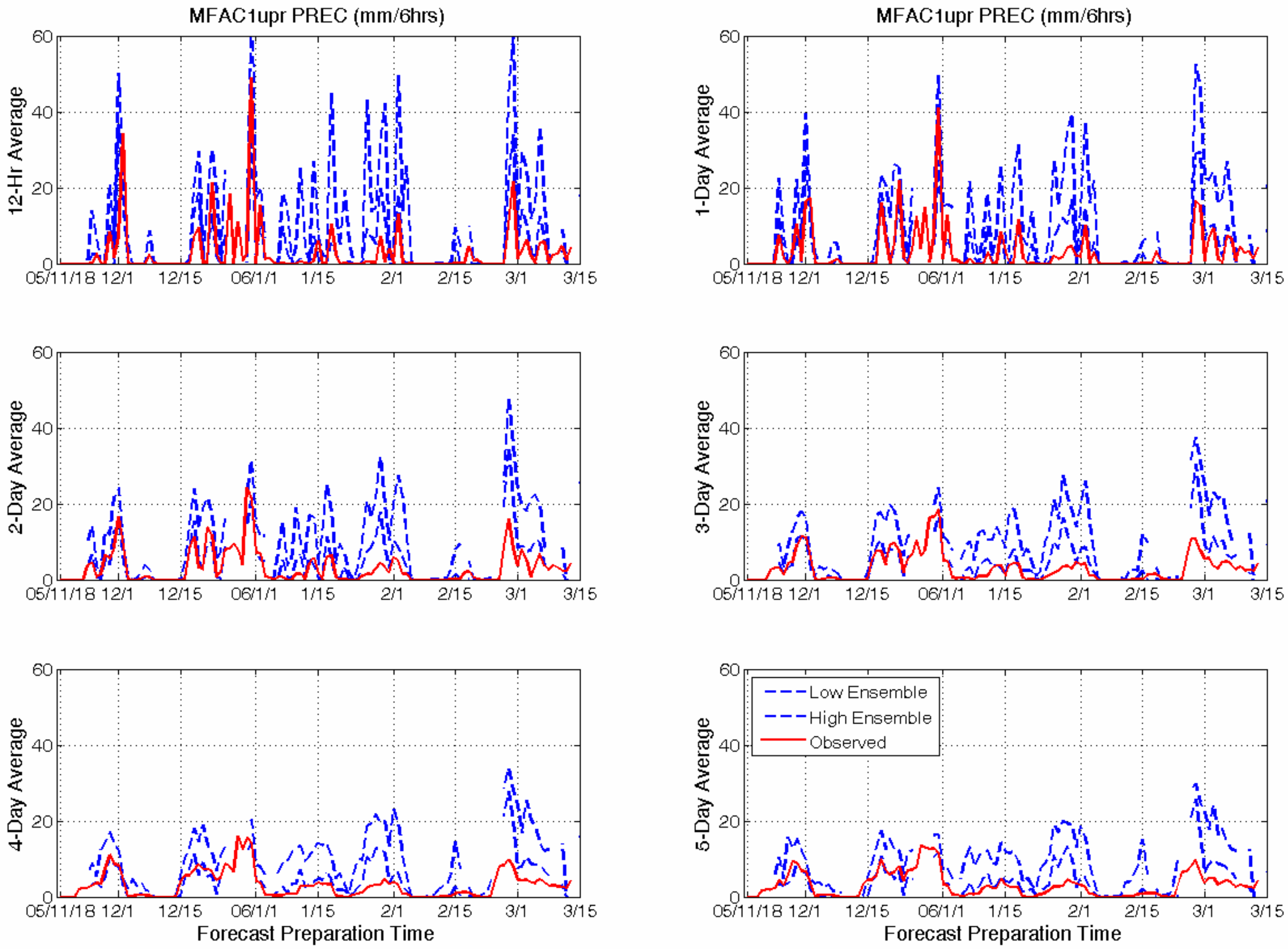
WET SEASON 2005-2006 ASSESSMENTS

- Simulation with observed MAP and MAT (CNRFC Estimates)
- MAP forecasts
- MAT forecasts
- Flow forecasts

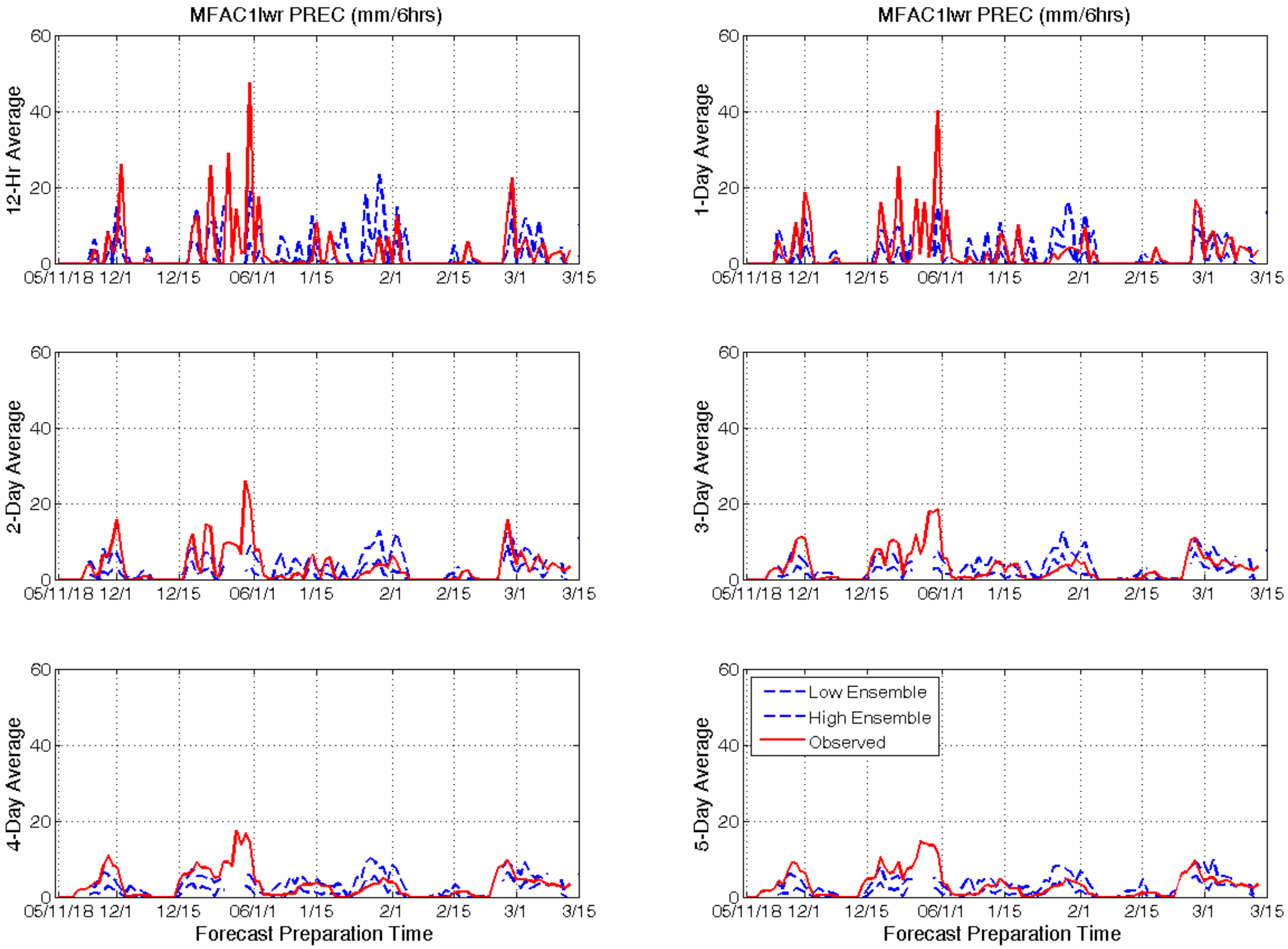
Notes: System was completed mid-season and download (NCEP and CNRFC) interruptions were common

No bias adjustments were made to precipitation, temperature and flow

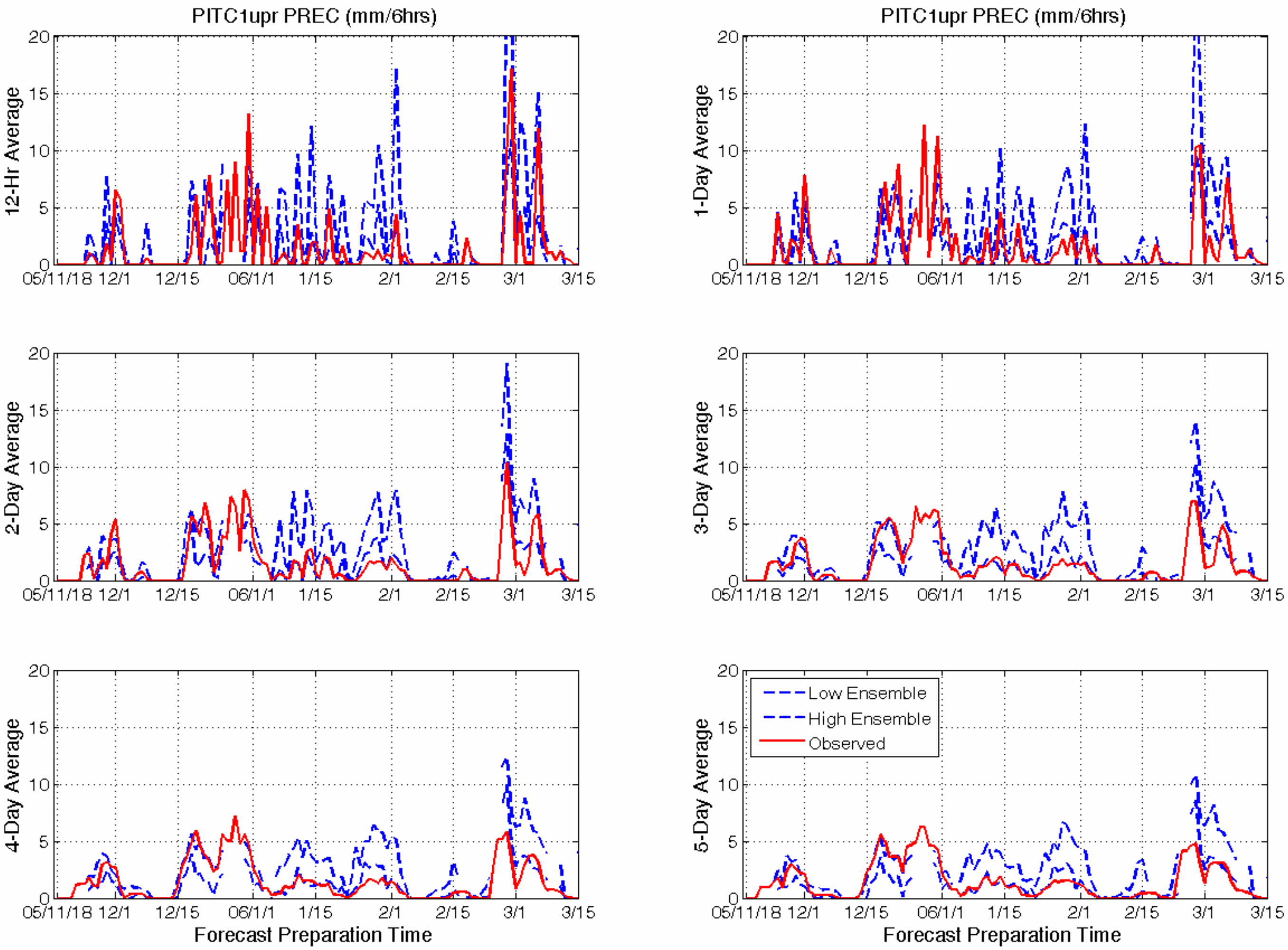
MAP Forecasts – Middle Fork American Upr



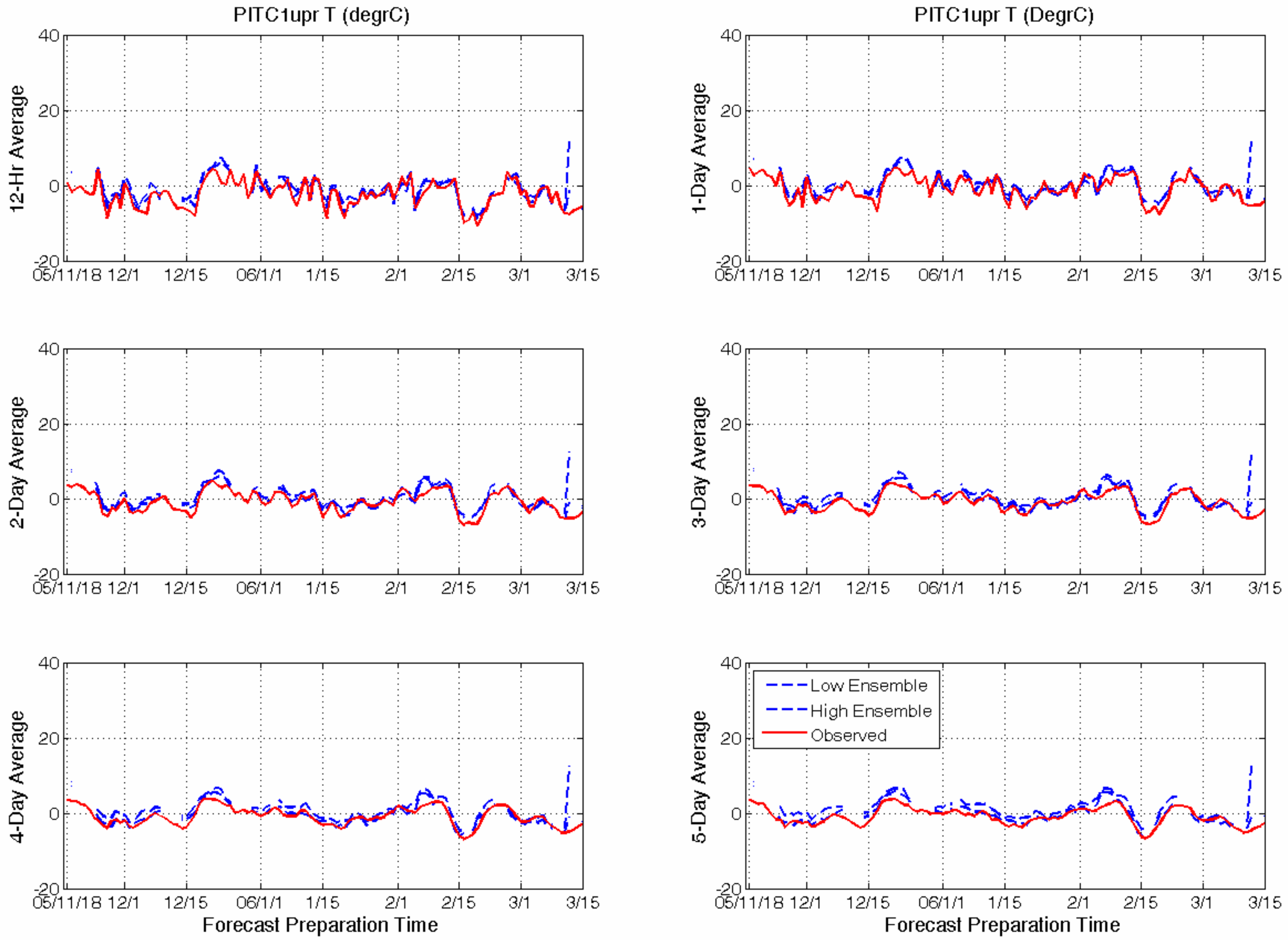
MAP Forecasts – Middle Fork American Lwr



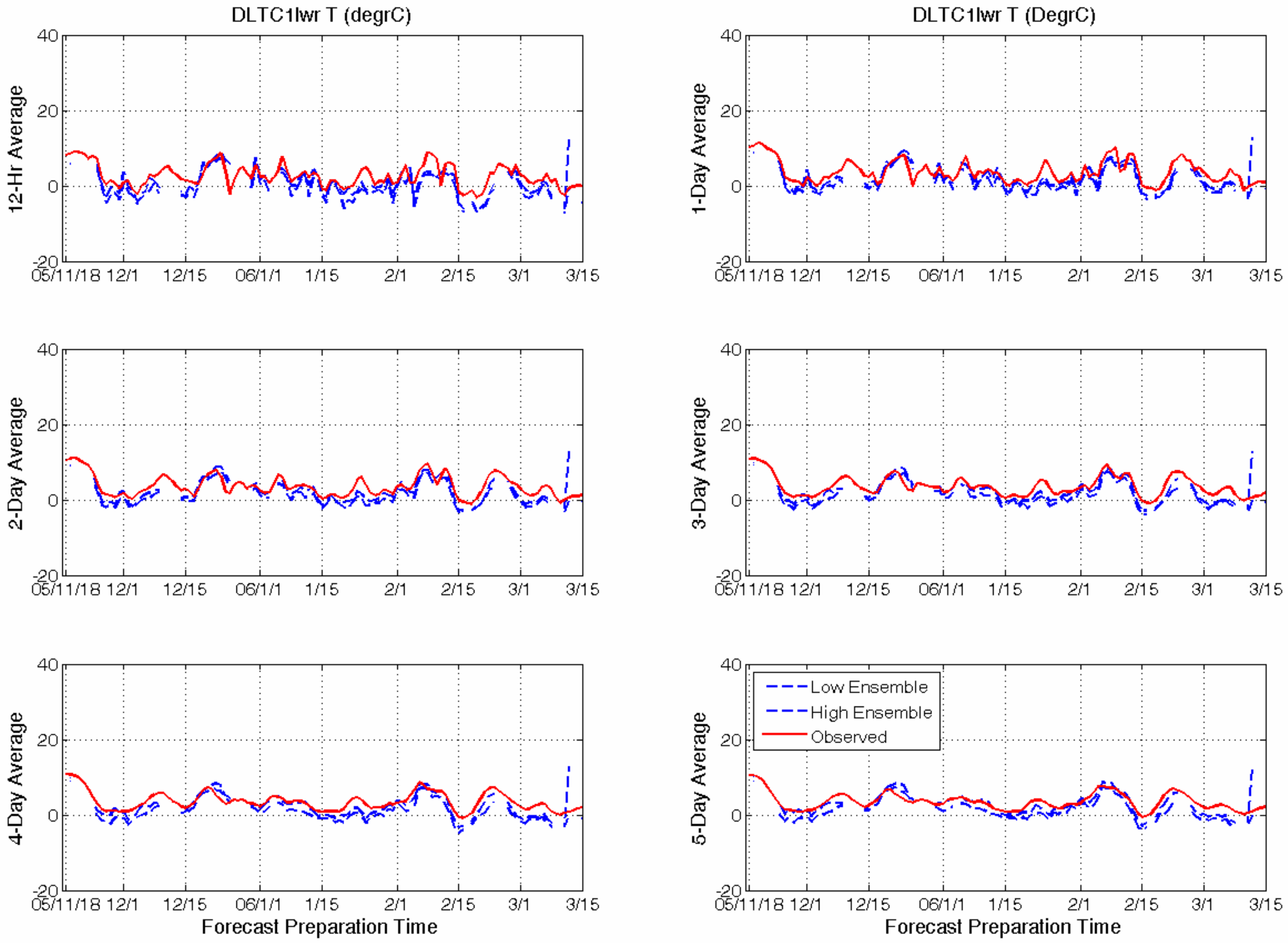
MAP Forecasts – Pit River Upr



MAT Forecasts – Pit River Upr



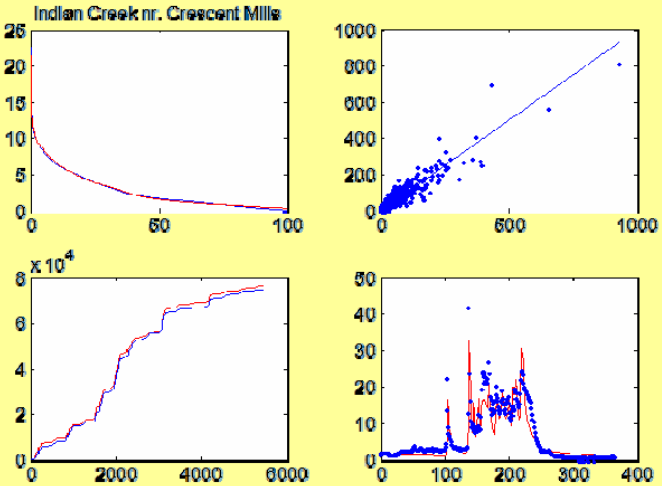
MAT Forecasts – Sac R at Delta Lwr



VALIDATION OF HYDROLOGIC COMPONENT SIMULATIONS

Oroville Drainage

Indian Creek



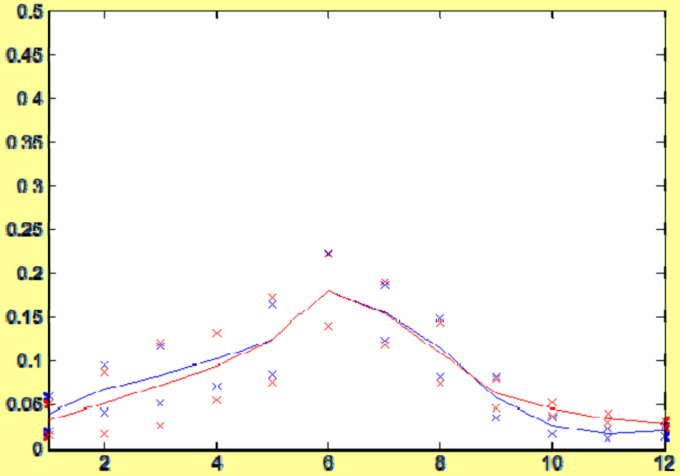
Box-Cox Transformation

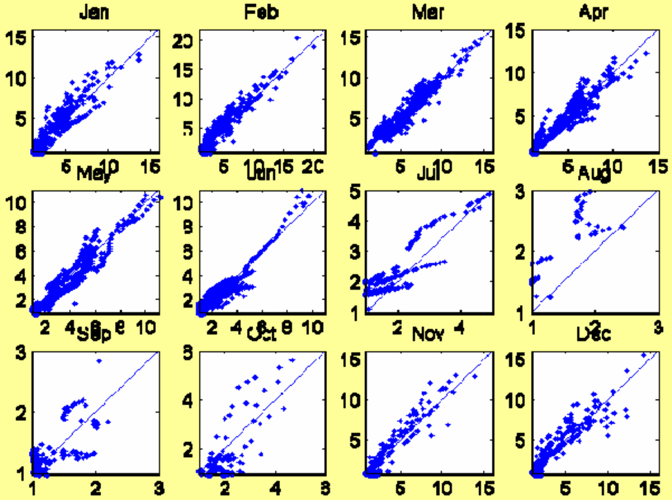
$Q_{\text{Tranform}} = (Q^{\lambda} - 1) / \lambda$

$\lambda = 0.3$

Blue Observation

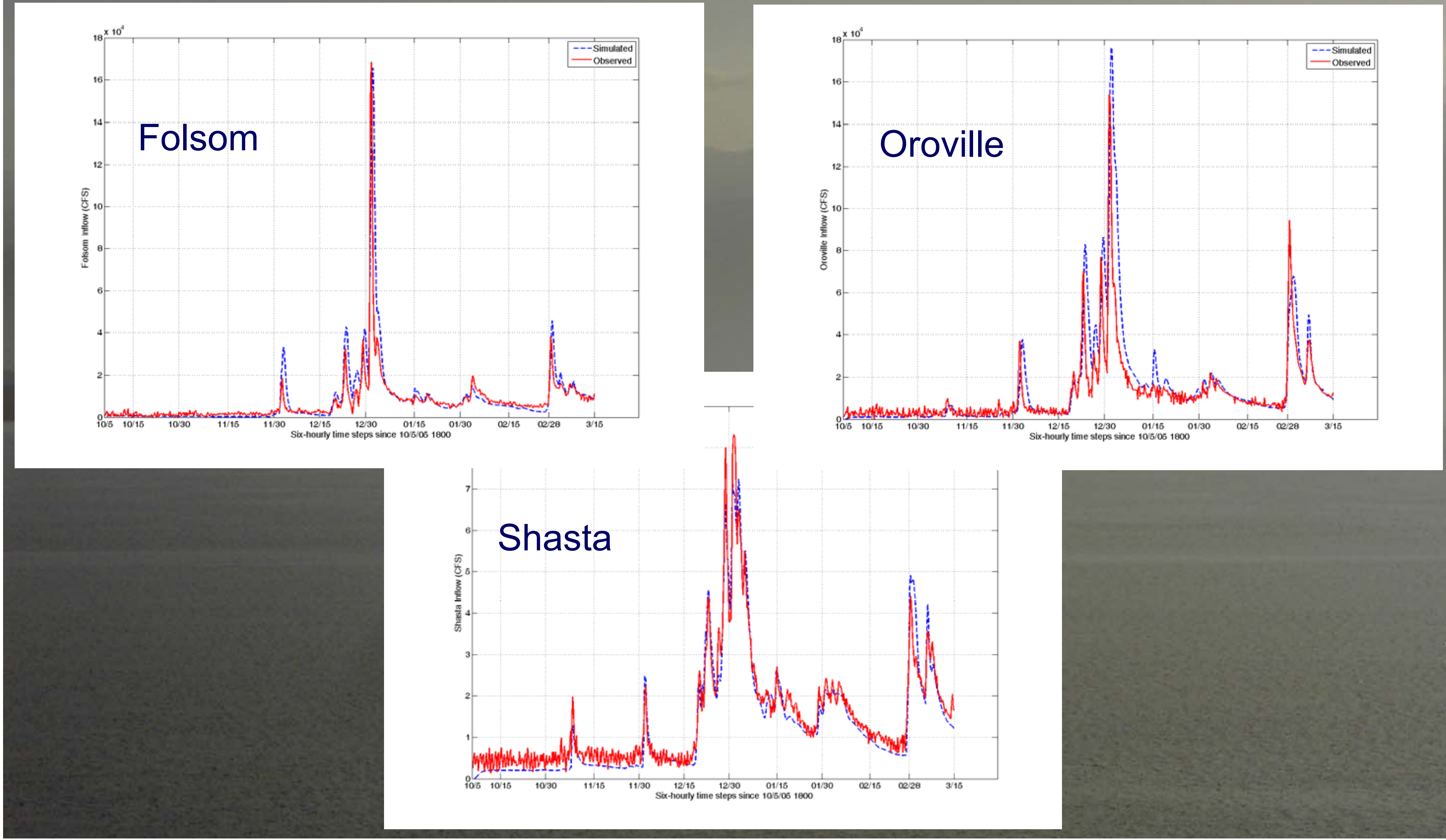
Red Simulation



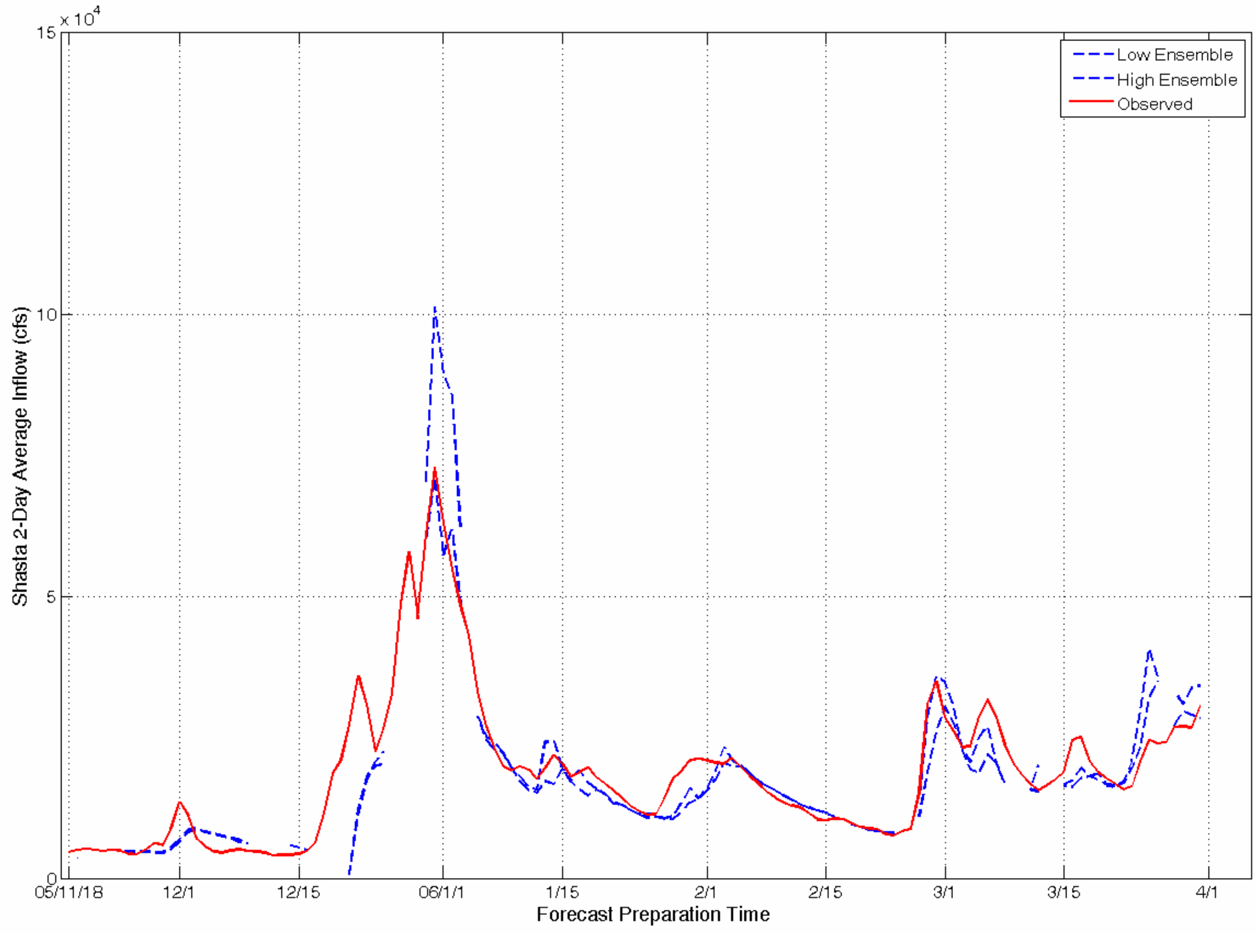


VALIDATION OF HYDROLOGIC COMPONENT SIMULATIONS

2005 – 2006 Wet Season Oct - March

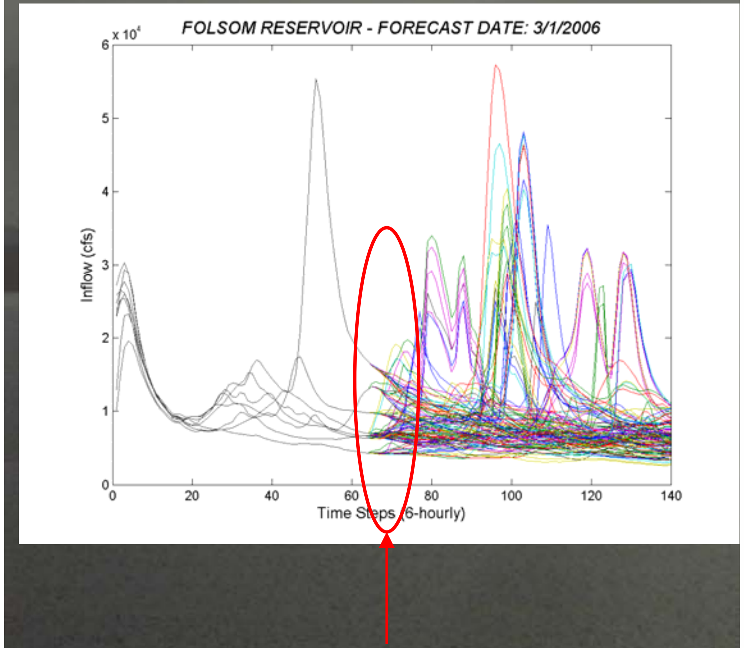


Shasta Forecast Inflows
(Bias adjusted precipitation)

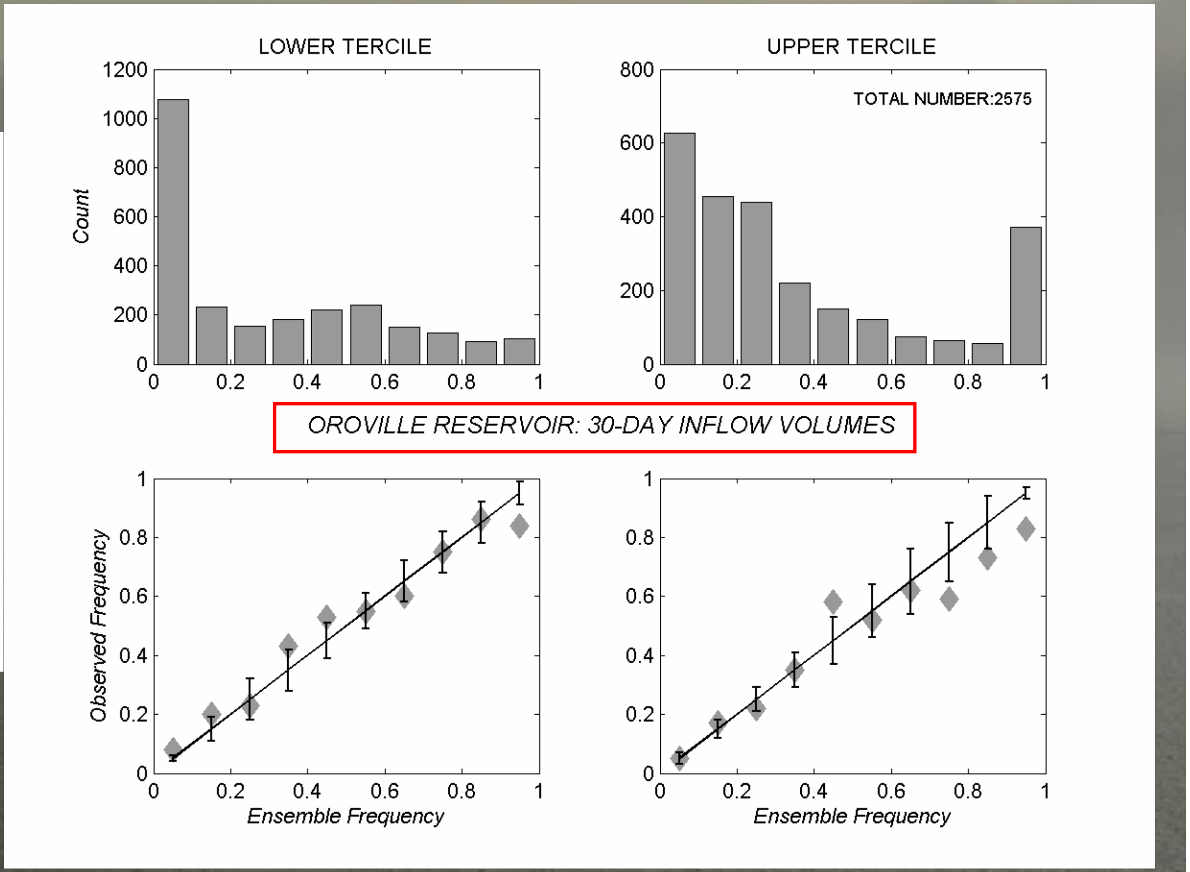


Longer Lead Time Forecasts

Retrospective Runs ESP: 1961 - 1997



Hydrology State Match

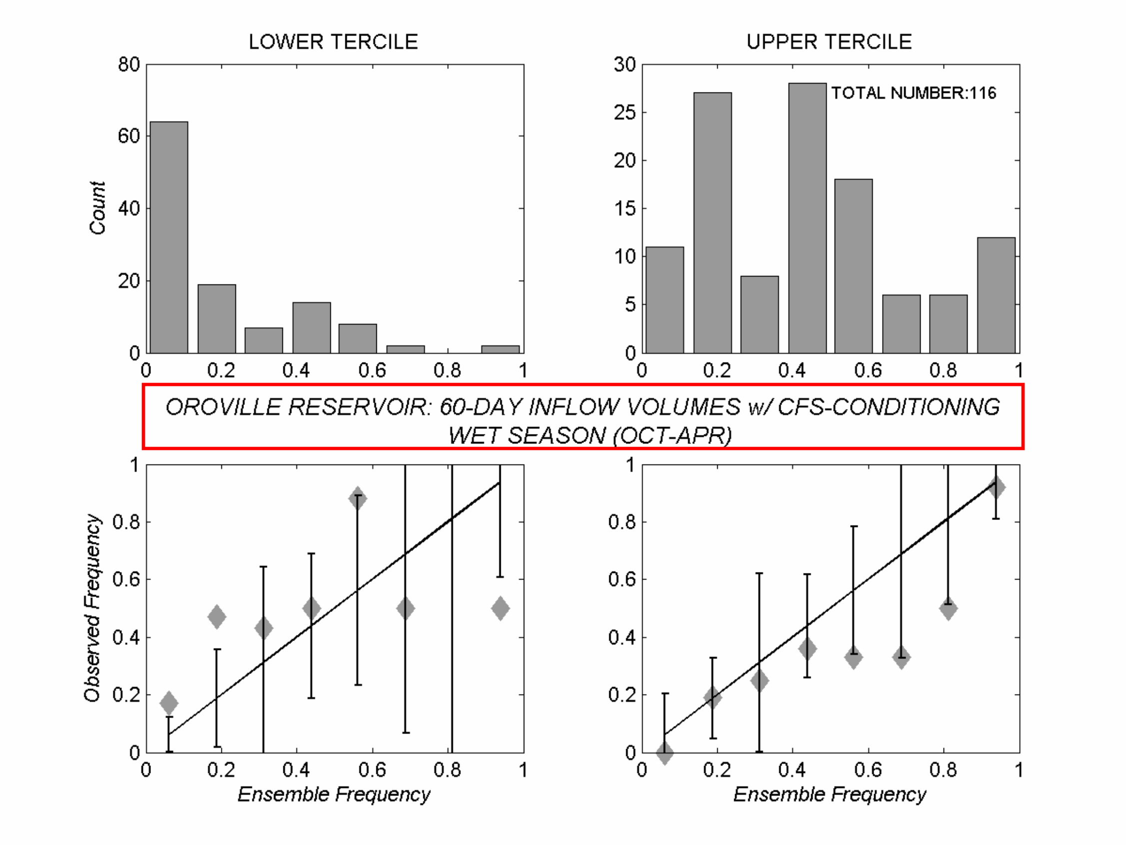


Longer Lead-Time Forecasts

Retrospective Runs ESP conditioned on CFS: 1981 - 2003

Conditioning on CFS Ensembles:

1. Probabilistic approach that requires historical forecasts
2. Includes hydrologic model error distributions

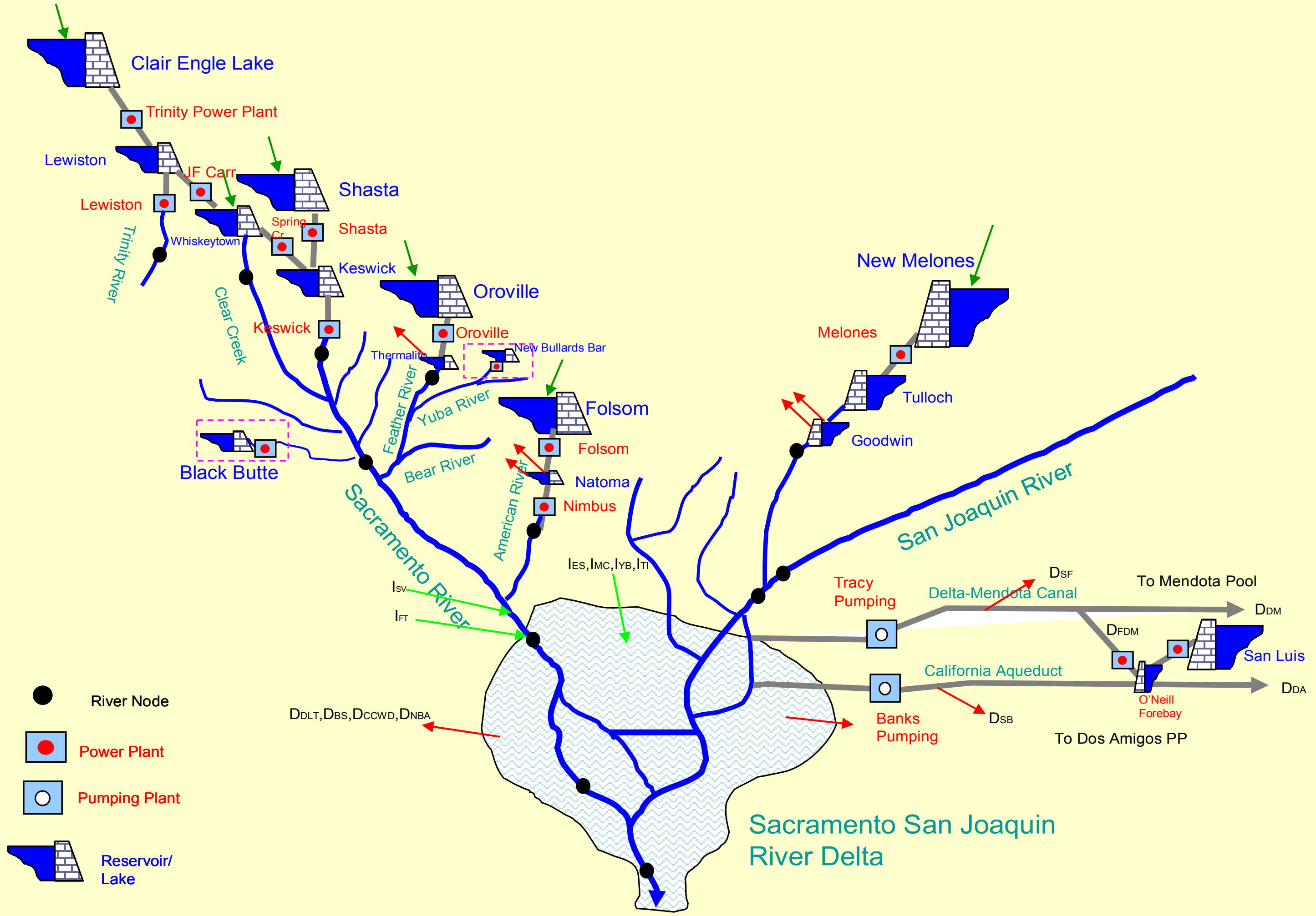


Forecast Component Assessments

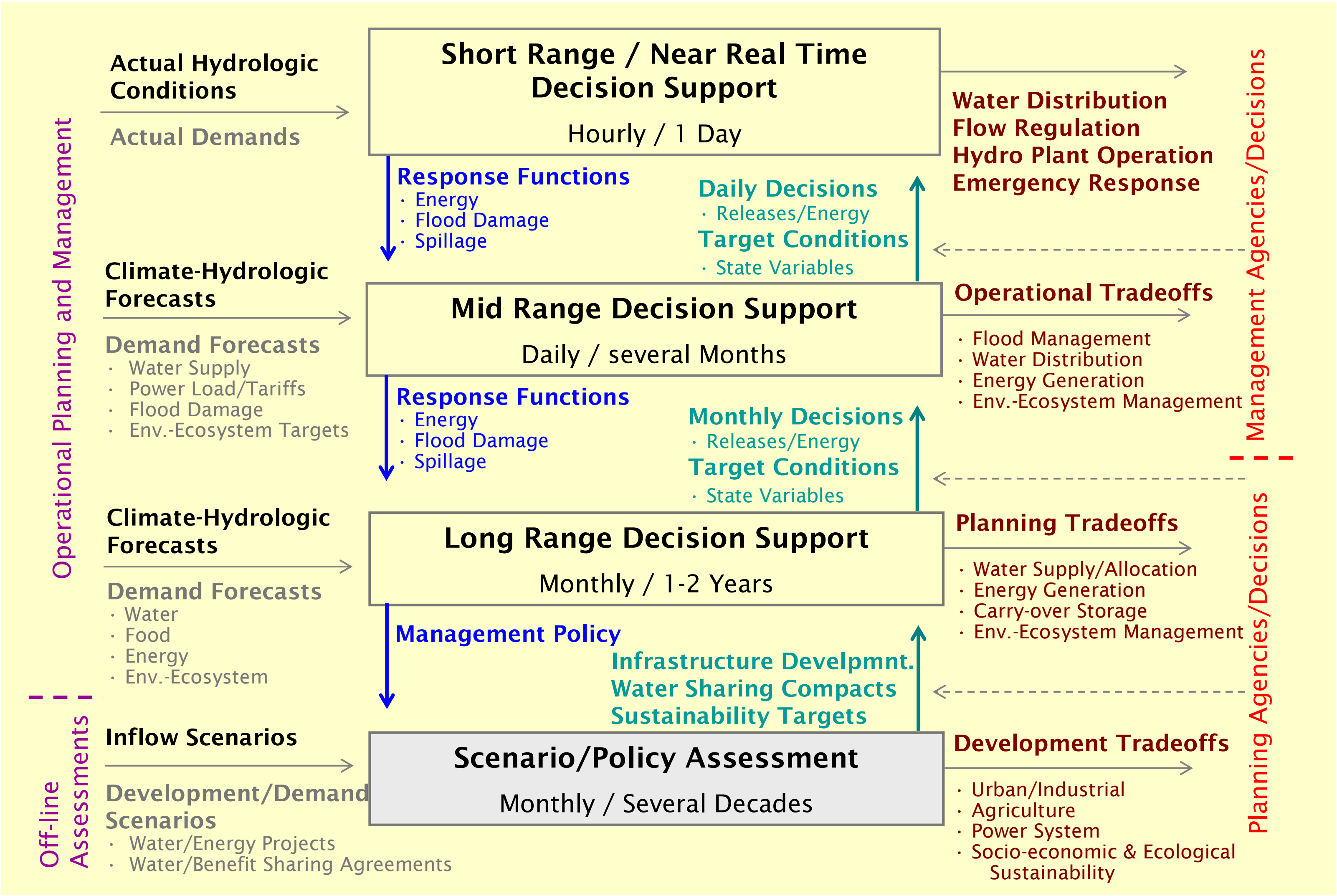
- INFORM Forecast component has skill for MAP, MAT, Reservoir-Inflows and for a range of lead times.
- More ensembles and additional assessments with real time forecasts and ensuing adjustments during 2-3 more wet seasons would further improve the reliability of this component.

More Details on: http://www.hrc-lab.org Under project INFORM

Decision Component



Decision Component



Operational Planning and Management

Off-line Assessments

Actual Hydrologic Conditions

Actual Demands

Short Range / Near Real Time Decision Support

Hourly / 1 Day

Water Distribution
Flow Regulation
Hydro Plant Operation
Emergency Response

Response Functions
- Energy
- Flood Damage
- Spillage

Daily Decisions
- Releases/Energy

Target Conditions
- State Variables

Climate-Hydrologic Forecasts

Demand Forecasts
- Water Supply
- Power Load/Tariffs
- Flood Damage
- Env.-Ecosystem Targets

Mid Range Decision Support

Daily / several Months

Operational Tradeoffs
- Flood Management
- Water Distribution
- Energy Generation
- Env.-Ecosystem Management

Response Functions
- Energy
- Flood Damage
- Spillage

Monthly Decisions
- Releases/Energy

Target Conditions
- State Variables

Climate-Hydrologic Forecasts

Demand Forecasts
- Water
- Food
- Energy
- Env.-Ecosystem

Long Range Decision Support

Monthly / 1-2 Years

Planning Tradeoffs
- Water Supply/Allocation
- Energy Generation
- Carry-over Storage
- Env.-Ecosystem Management

Management Policy

Infrastructure Develpmnt.
Water Sharing Compacts
Sustainability Targets

Inflow Scenarios

Development/Demand Scenarios
- Water/Energy Projects
- Water/Benefit Sharing Agreements

Scenario/Policy Assessment

Monthly / Several Decades

Development Tradeoffs
- Urban/Industrial
- Agriculture
- Power System
- Socio-economic & Ecological Sustainability

Management Agencies/Decisions

Planning Agencies/Decisions

Decision Component

Retrospective Simulations - Assessments

Reservoirs	**Assessment Criteria**	**ESP**		**CCF**		**Perfect For.**
		Stochastic	Deterministic	Stochastic	Deterministic	
Folsom	Inflow (cfs)	3382	3382	3382	3382	3382
	Spillage (cfs)	334	422	297	401	270
	Energy (GWH)	1.77	1.76	1.72	1.77	1.84
	Max. Release (cfs)	116791	121841	99905	116791	59968
	Max. Damage ($)	220,400,000	842,000,000	0	220,400,000	0
Oroville	Inflow (cfs)	5634	5634	5634	5634	5634
	Spillage (cfs)	541	554	468	549	310
	Energy (GWH)	5.46	5.46	5.43	5.46	5.62
	Max. Release (cfs)	169254	169394	133303	146799	88773
	Max. Damage ($)	0	0	0	0	0
Shasta	Inflow (cfs)	7800	7800	7800	7800	7800
	Spillage (cfs)	464	694	431	685	329
	Energy (GWH)	6.68	6.67	6.61	6.66	6.92
	Max. Release (cfs)	109937	125837	109937	125837	100590
	Max. Damage ($)	0	0	0	0	0
Trinity	Inflow (cfs)	1779	1779	1779	1779	1779
	Spillage (cfs)	134	158	119	154	114
	Energy (GWH)	1.08	1.09	1.05	1.09	1.12
	Max. Release (cfs)	31081	31081	31081	31081	31081
	Max. Damage ($)	0	0	0	0	0

Decision Component

Spring 2006 Case Study Data

- Forecasted inflows were provided with start date March 1st, 2006 (112 traces, 9 month horizon, and five locations: Clair Engle Lake, Shasta, Oroville, Folsom, and Yuba);

- Historical monthly average values are used for locations where forecasted inflows are not available;

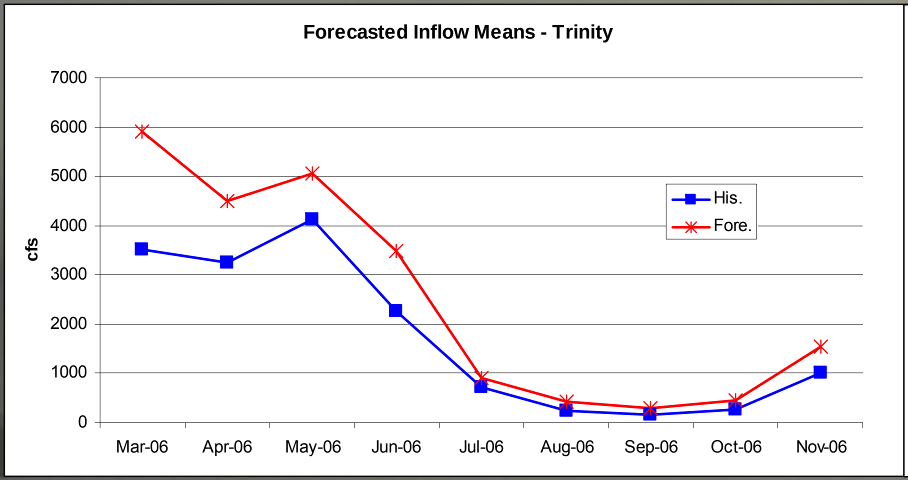
- Monthly reservoir parameters and constraints (max, min, and target storage levels; evaporation rates);

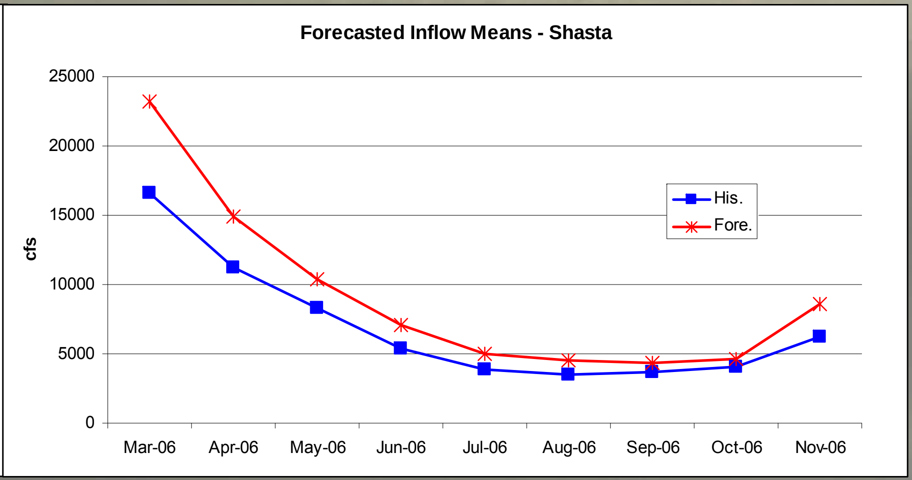
- Minimum river flow requirements; and

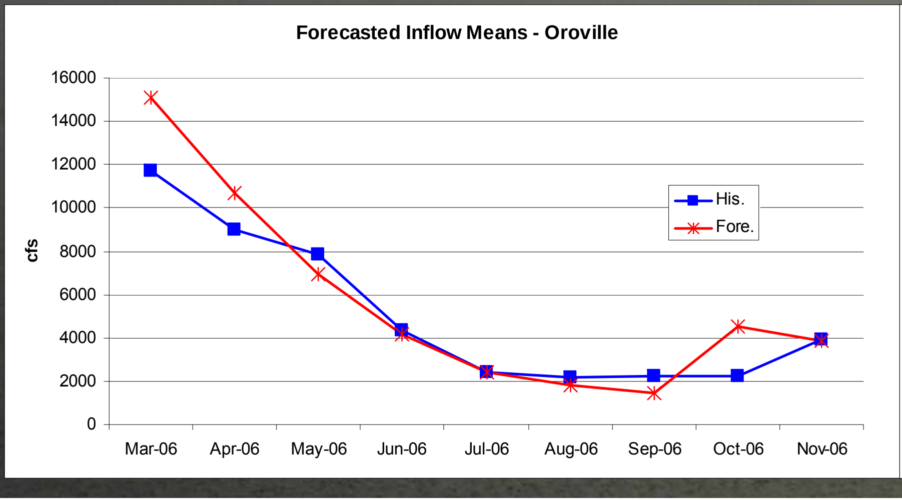
- Base monthly demands at all locations.

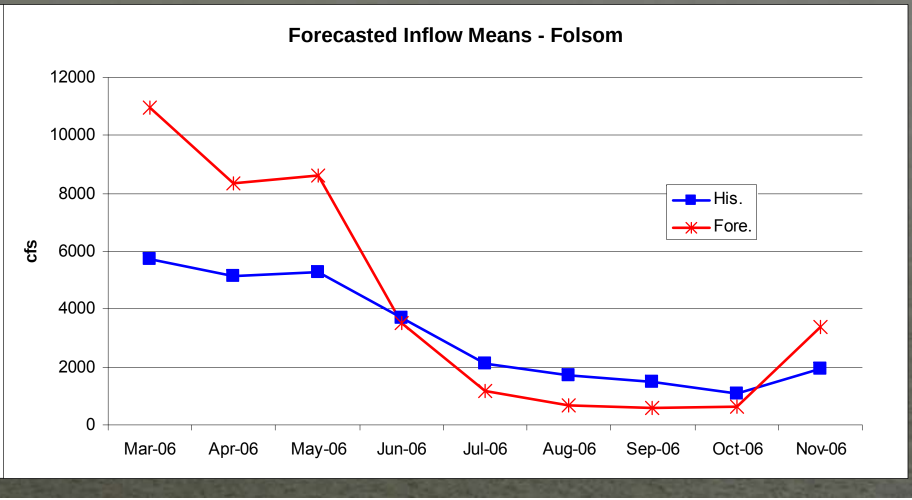
Decision Component

Spring 2006 Forecast: Wetter Spring in the Mean


Forecasted Inflow Means - Trinity


Forecasted Inflow Means - Shasta


Forecasted Inflow Means - Oroville

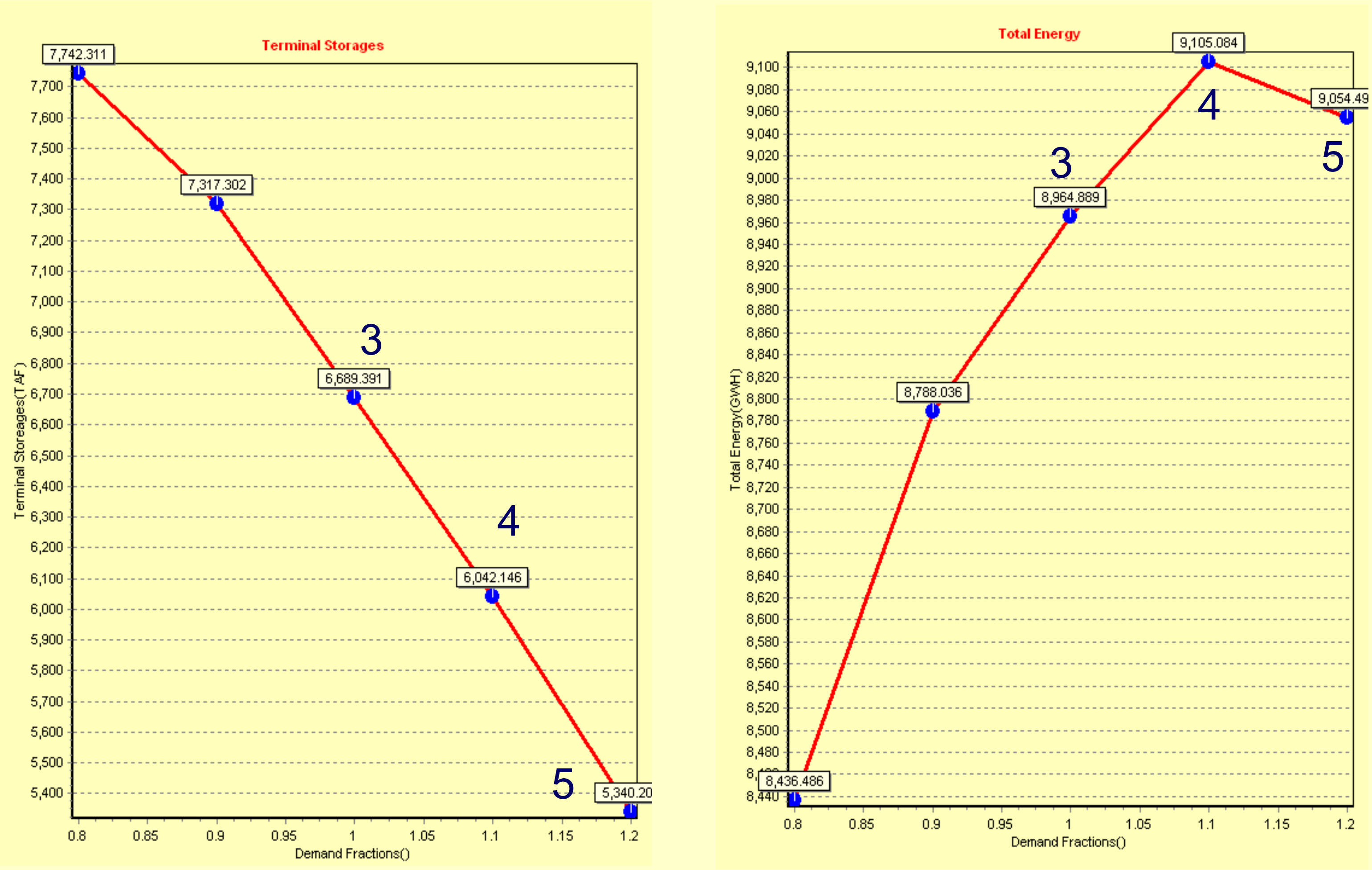

Forecasted Inflow Means - Folsom

Decision Component

INFORM Generated Forecast-Based Decision Trade-Offs (examples) as Functions of Fractional Change in Demand Targets

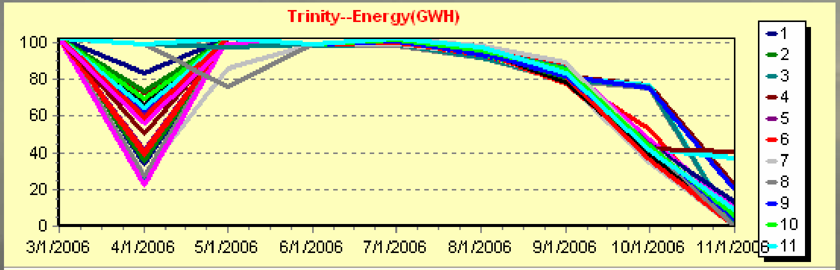
a) Carry-over Storage vs. Demand

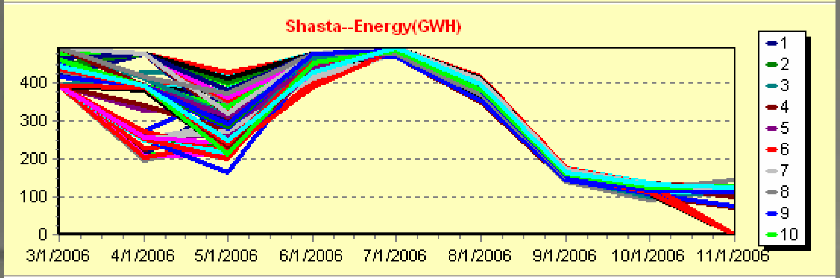
b) Energy Generation vs. Demand

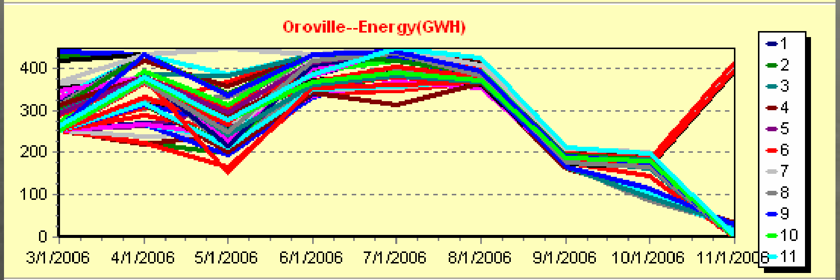


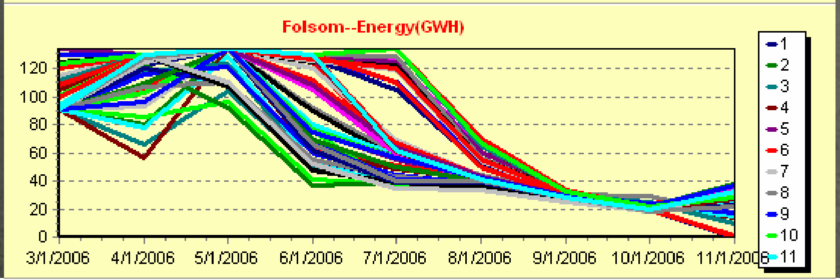
Decision Component

Example Display: Energy Generation Sequences associated with Tradeoff Point 3



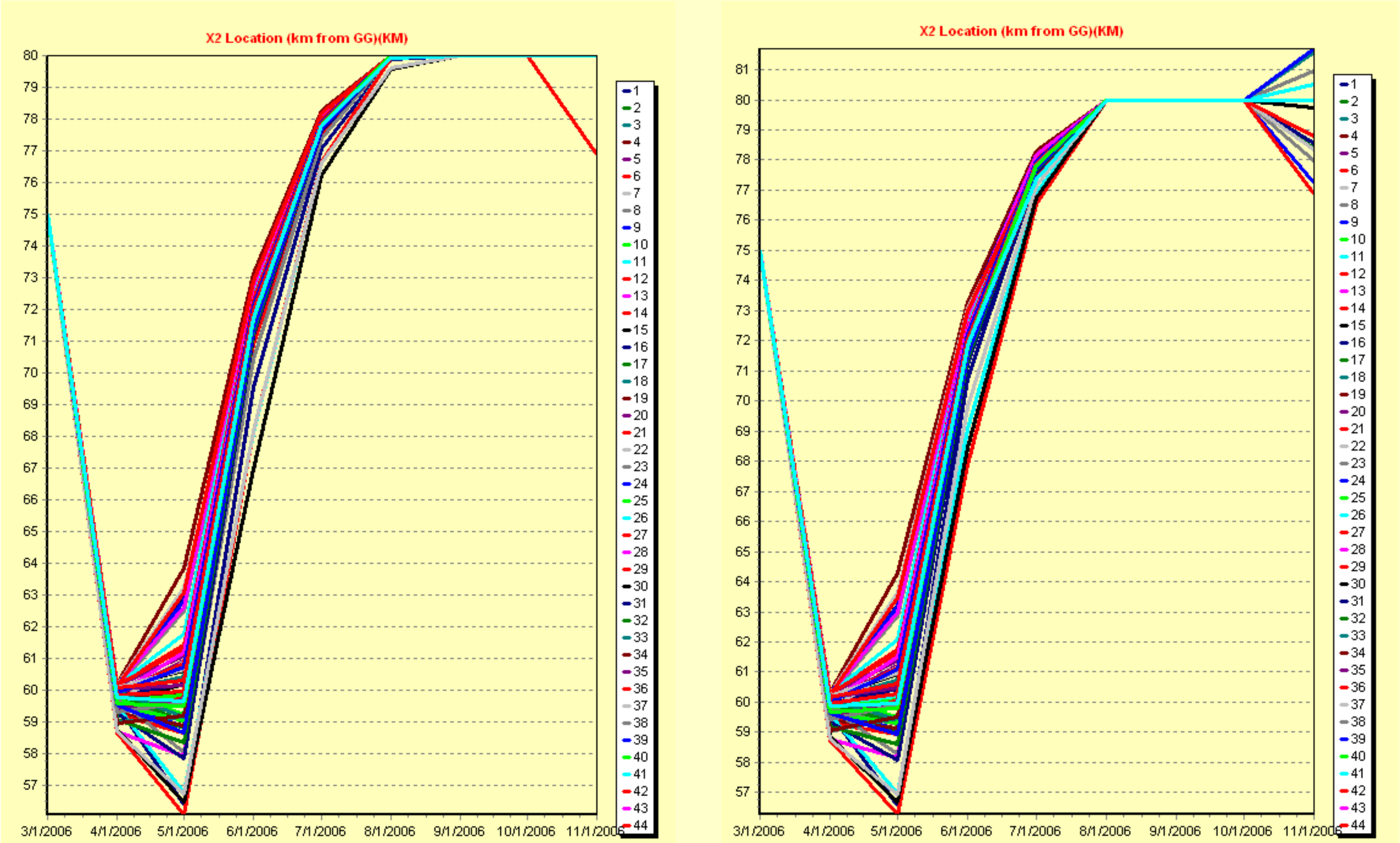






Decision Component

Saline Water Front Location from Golden Gate Bridge


a) Tradeoff Point #3

b) Tradeoff Point #5

Decision Component

Effect of INFORM Based Information for Spring 2006

Under current storage levels and using the INFORM Forecast component ensemble forecasts, if the INFORM system was used to make actual decisions on March 1, 2006 (on the basis of trade-offs 3, 4 and 5 for a 9-% reliability), **the system could meet up to 10-15% more than the base demand targets**

Main Overarching Conclusion

Integrated forecast-management systems are realizable as operational decision support tools for the management and planning of regional water resources.

They assist water managers to translate forecasts and their uncertainty into risk-based policies

Key ingredients:

1. Dynamic downscaling of ensemble operational atmospheric forecasts
2. Explicit characterization of forecast uncertainty for use by decision component
3. Decision component with ability to incorporate decisions over multiple time scales and for several multi-objective reservoirs

HRC Team Members

- Theresa Carpenter, Hydrologic Modeling
- Eylon Shamir, Snow Modeling
- Jason Sperfslage, Computer Systems Programmer
- Steve Taylor, Statistical Validation
- Jianzhong Wang, Numerical Mesoscale Modelling

Funding Agencies

- CEC – PIER
- California Bay Delta Authority
- National Oceanic and Atmospheric Administration
- USA Corps of Engineers