Integrated Forecast and Reservoir Management: The INFORM System

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PRESENTATION FOCUS

Reservoir Management in Northern California under climatic variability and change

A system of reservoirs modulates the climatic and weather variability in order to produce downstream benefits:

- hydroelectric power production
- flood damage mitigation
- water conservation for municipal, industrial and agricultural supply
- ecosystem benefits
- others

Reservoir effectiveness is substantially influenced by

- climatic variability and trends
- demand variability and trends
- changing water markets

Important target of reservoir management is to

- maximize water use efficiency
  (individual uses, individual reservoirs, system)

The Integrated Forecast and Management Project (INFORM) for Northern California

Prototype Demonstration Project since 2002
(Feasibility Studies in mid- and late-90s)

Georgakakos et al. 2014: J. of Hydrology, ***in press*** *(http://dx.doi.org/10.1016/j.jhydrol.2014.05.032)*
Georgakakos et al. 2014: J. of Hydrology, ***accepted*** *(upstream regulation effects)*
Georgakakos et al. 2012a-b: J. of Hydrology, ***412-413****, 34-46 & 47-62.*
Georgakakos and Graham 2008: J. Applied Meteorology and Climatology, ***47****, 1297-1321.*
Graham et al. 2006: Adv. Water Resources, ***29****, 1665-1677.*
Georgakakos et al. 2005: EOS, ***86****(12), 122-127.*
Wang and Georgakakos 2005: Monthly Weather Review, ***133****, 3-19.*
Yao and Georgakakos 2001: J. of Hydrology, ***249****, 176-196*
Carpenter and Georgakakos 2001: J. of Hydrology, ***249****, 148-175.*
Georgakakos et al. 1998: Water Resources Research, ***34****(4), 799-821.*

http://www.energy.ca.gov/pier/project_reports/CEC-500-2006-109.html
http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2010-051
http://www.hrc-lab.org/projects (follow link to INFORM)

The Present Talk is an Introduction

SPONSORS-COLLABORATORS

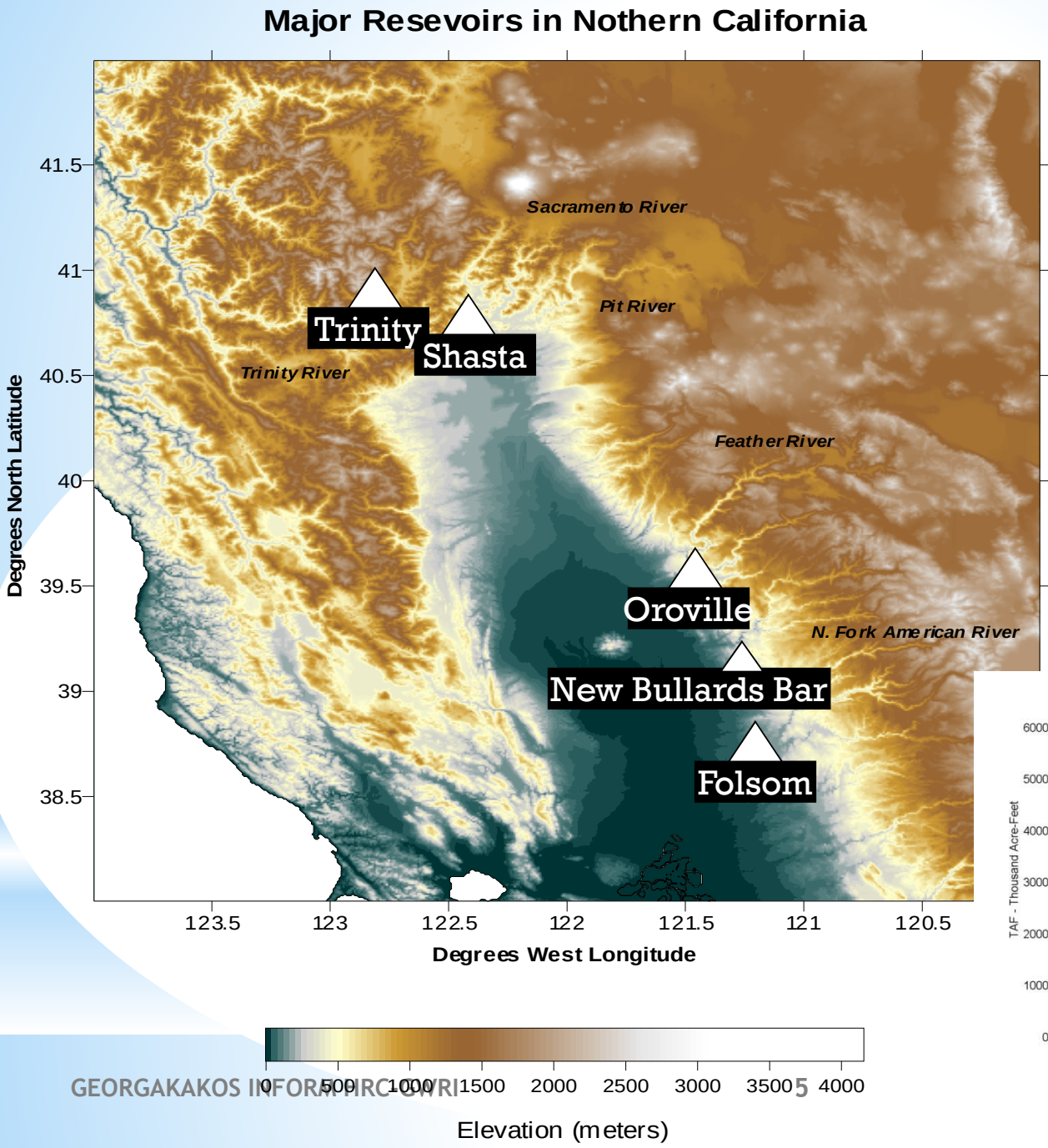
Sponsors:

CALFED Bay Delta Authority
California Energy Commission
National Oceanic and Atmospheric Administration
(CPO and NWS/OHD)

Members of Oversight and Implementation Committee:

California Department of Water Resources
California-Nevada River Forecast Center
Sacramento Area Flood Control Agency
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
National Centers of Environmental Prediction (NCEP)
GIT
HRC

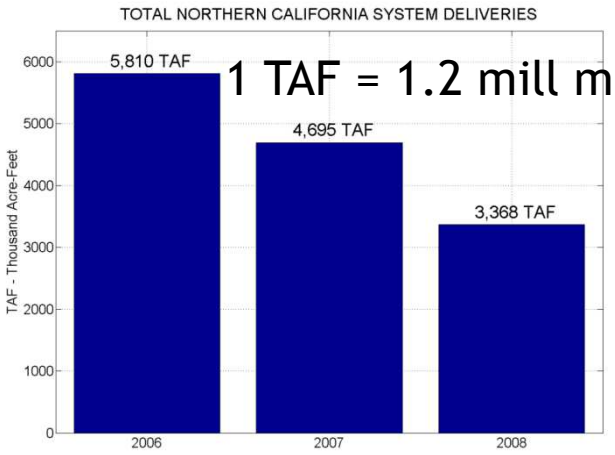
INFORM Region



VISION

Improve reservoir management in Northern California using climate, hydrologic, and decision science

CHALLENGE



1 TAF = 1.2 mill m^3

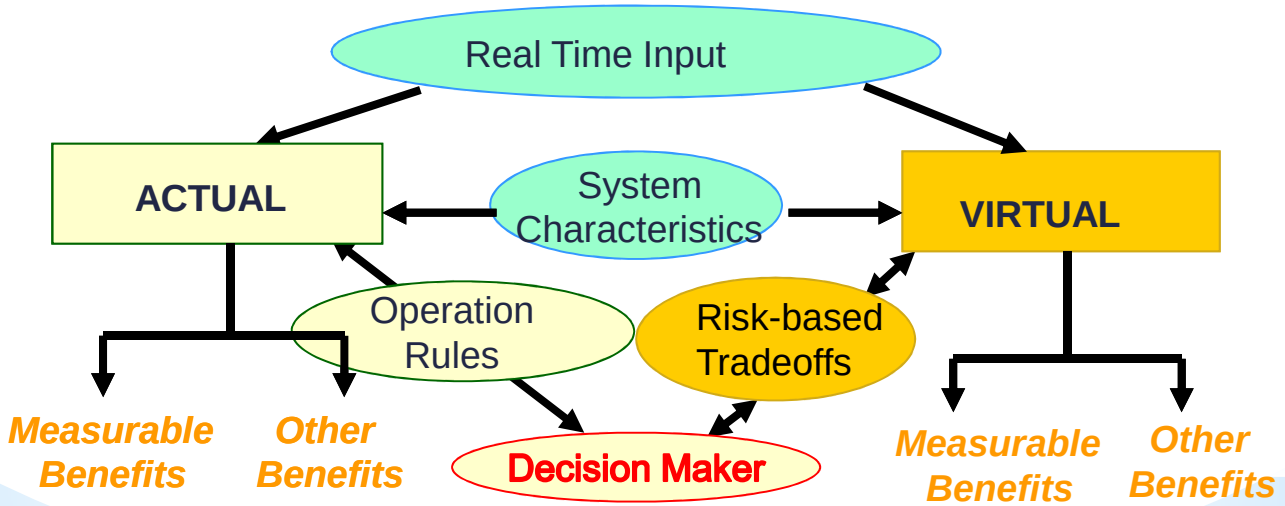
INFORM GOALS AND OBJECTIVES

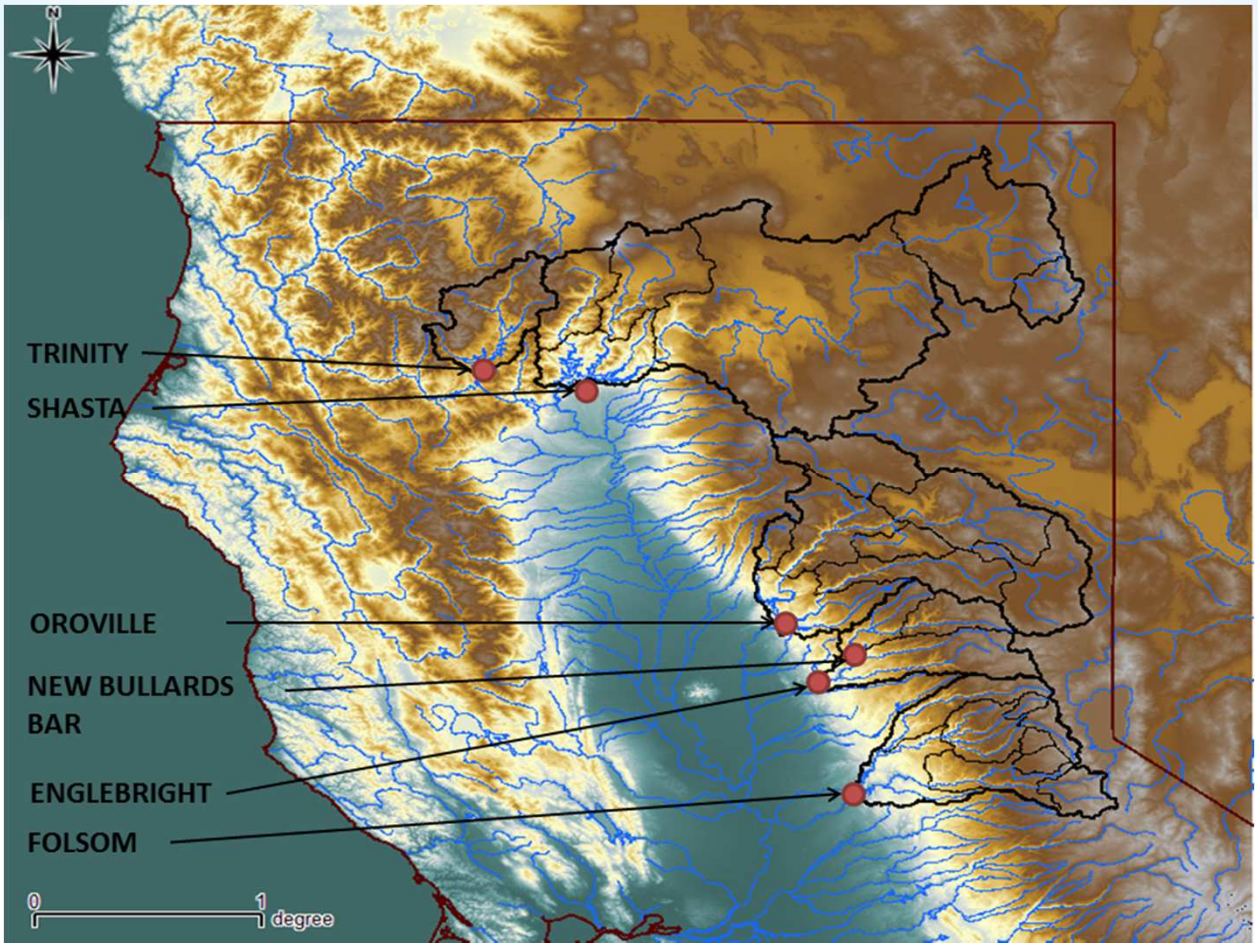
Implement an integrated forecast-management system for the Northern California reservoirs using real-time data and operational forecast models

(Aspects of actual system to be represented were selected in collaboration with Agencies)

Perform tests with actual data and with management input

Demonstrate the utility of climate and hydrologic forecasts for water resources management in Northern California for several years




N
TRINITY
SHASTA
OROVILLE
NEW BULLARDS BAR
ENGLEBRIGHT
FOLSOM
0
1
degree

INFORM SYSTEM COMPONENTS

Forecast component

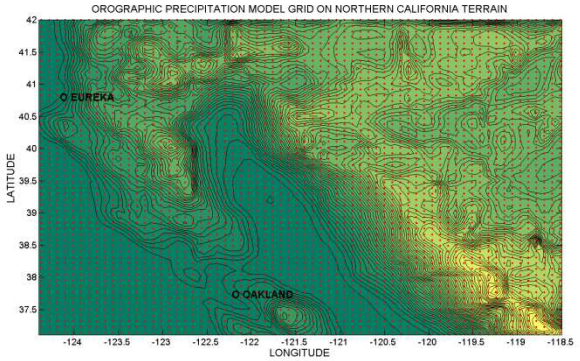
ATM DATA

ATM FORECASTS

Adjustments

HYDROLOGIC MODEL ⟷ NWS-CNRFC FORECASTERS

Ensemble Forecast

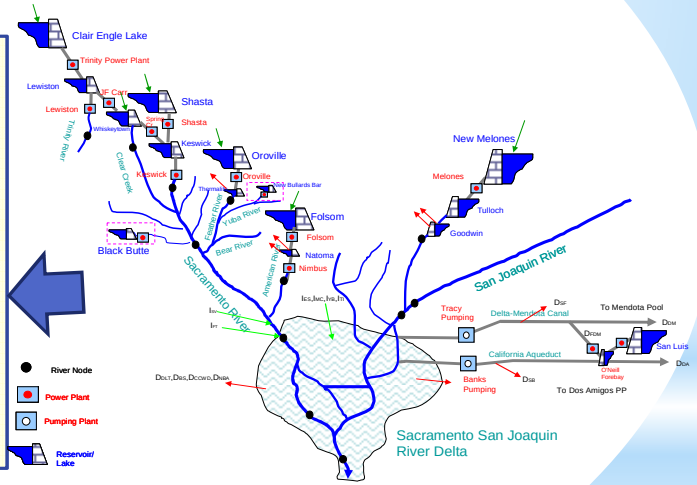


Management component

DECISION MODEL ⟷ RESERVOIR MANAGERS

Release Schedule

ASSESSMENT SYSTEM

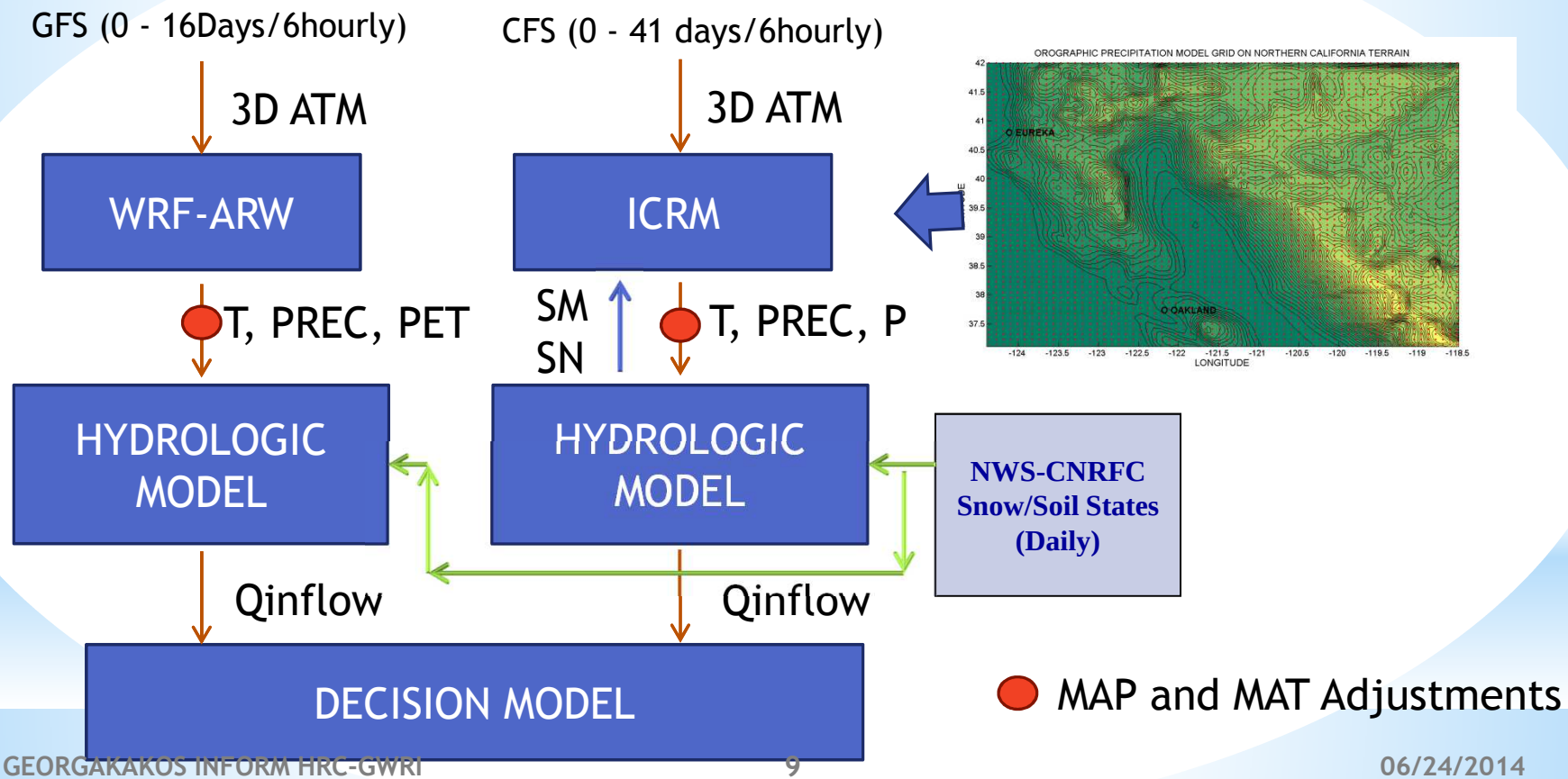


Management Benefits

Water Supply, Flood Control
Hydropower, Env. Protection, etc.

Forecast Component Models (0 – 41 Days)

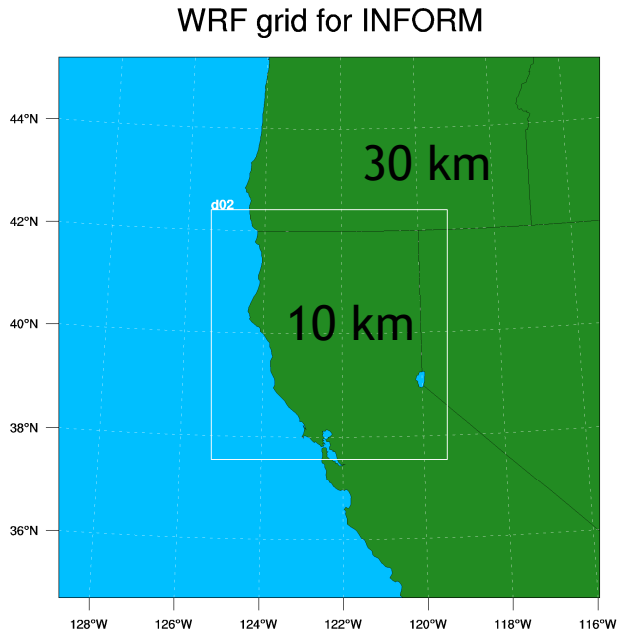
Integration with operational agency data, forecasts and models
NCEP(GFS&CFS) and CNRFC(NWSRFS&CHPS)

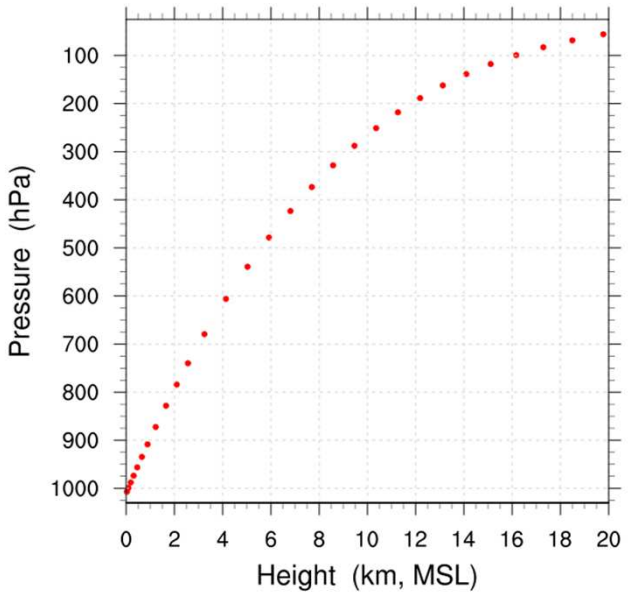


WEATHER RESEARCH AND FORECASTING (WRF) MODEL

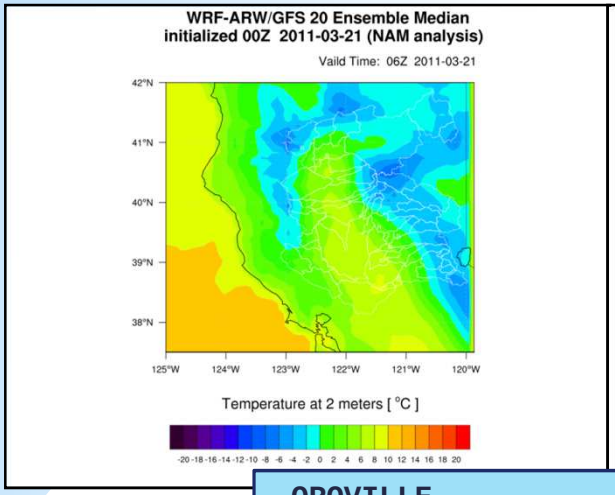
Version 3.2.1 of the Advanced Research WRF (ARW) dynamical core
(Twice daily out to 16 days w/ 6-hourly resolution output)

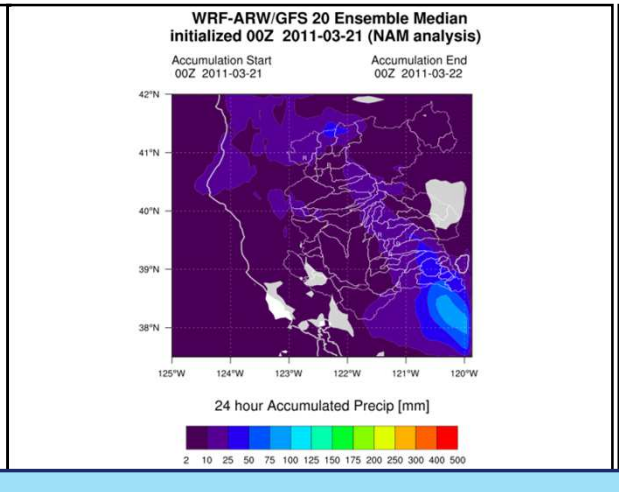
Boundary Conditions – Global Ensemble Forecast System (GEFS) (1º)
Initial Conditions – North American Model (NAM) analysis (12km)

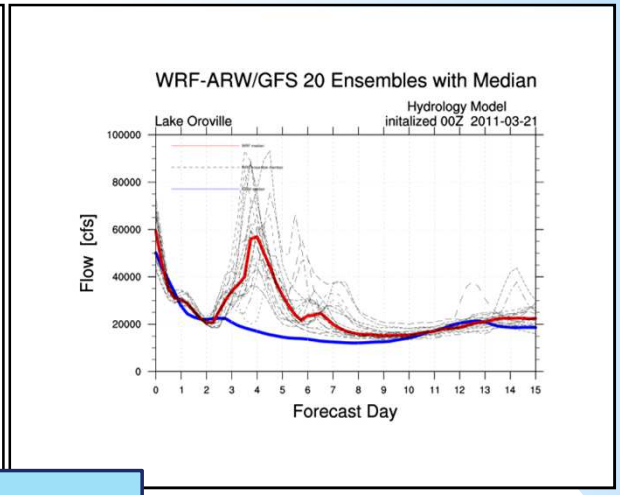




SHORT-TERM REAL TIME FORECAST EVALUATION - WRF







OROVILLE

NAME	MEANOBS	MEANSIM	STDVOBS	STDVSIM	CORREL
PLLC1UP	0.88	2.21	2.69	3.94	0.726
PLLC1LW	0.52	1.35	1.55	2.38	0.699
IIFC1UP	0.59	0.98	2.03	2.15	0.427
IIFC1LW	0.71	1.24	2.26	2.01	0.705
PLGC1UP	1.26	2.12	3.32	3.92	0.776
PLGC1LW	1.09	2.13	2.65	3.89	0.801
MFTC1UP	0.89	0.67	3.21	1.87	0.514
MFTC1LW	0.50	0.59	1.82	1.56	0.686
MRMC1UP	1.05	2.26	2.45	4.44	0.761
MRMC1LW	1.04	2.49	2.56	4.84	0.700
ORDC1UP	1.58	3.36	3.59	6.62	0.769
ORDC1LW	1.19	2.25	2.81	4.40	0.773
SCBC1UP	1.06	1.58	3.42	2.90	0.657
SCBC1LW	1.01	1.79	3.37	3.68	0.548
WBGC1UP	1.37	3.45	3.08	6.48	0.831
WBGC1LW	1.24	3.28	3.05	6.17	0.794
AVERAGES	**1.00**	**1.99**	**2.74**	**3.83**	**0.698**

WRF-ARW Median
20 Ensembles
1 Day Lead Time
Twice Daily Starts
2/20 – 3/15/2011

CLIMATE FORECAST SYSTEM – CFS1

(2.5 degrees grid; 12 hour resolution)

Available

Pressure (hPa)	Z	U	V	P_{WAT}
1000	X	G	G	
850	X	X	X	
700	X	G	G	
500	X	G	G	
200	X	G	G	
				X

Minimum Required

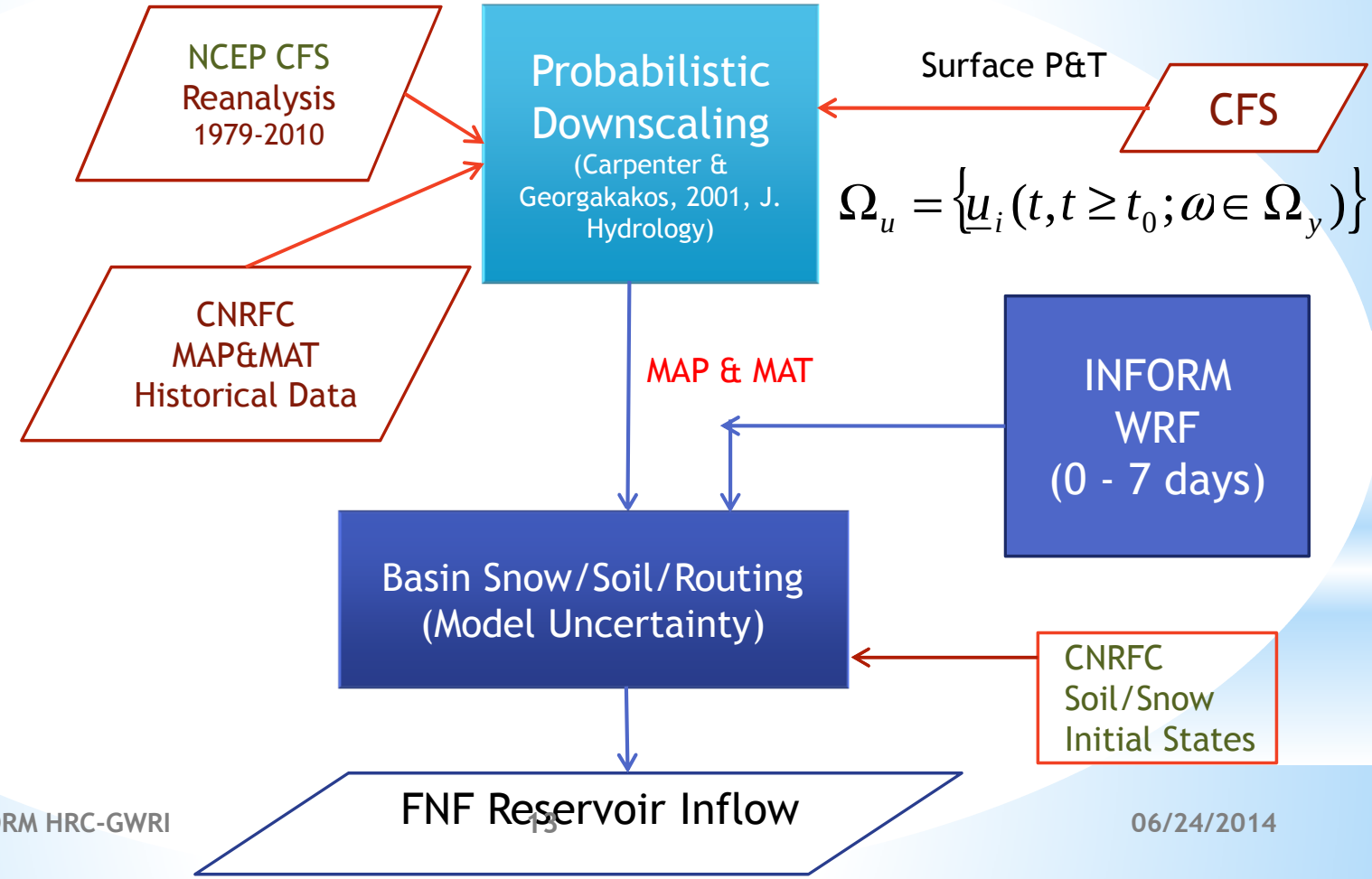
Pressure (hPa)	Z	T	Q	U	V
1000	X	D	D	X	X
850	X	D	D	X	X
700	X	D	D	X	X
500	X	D	D	X	X
400	X	D	D	D	D
200	X	D	D	X	X

Principal Component Regression

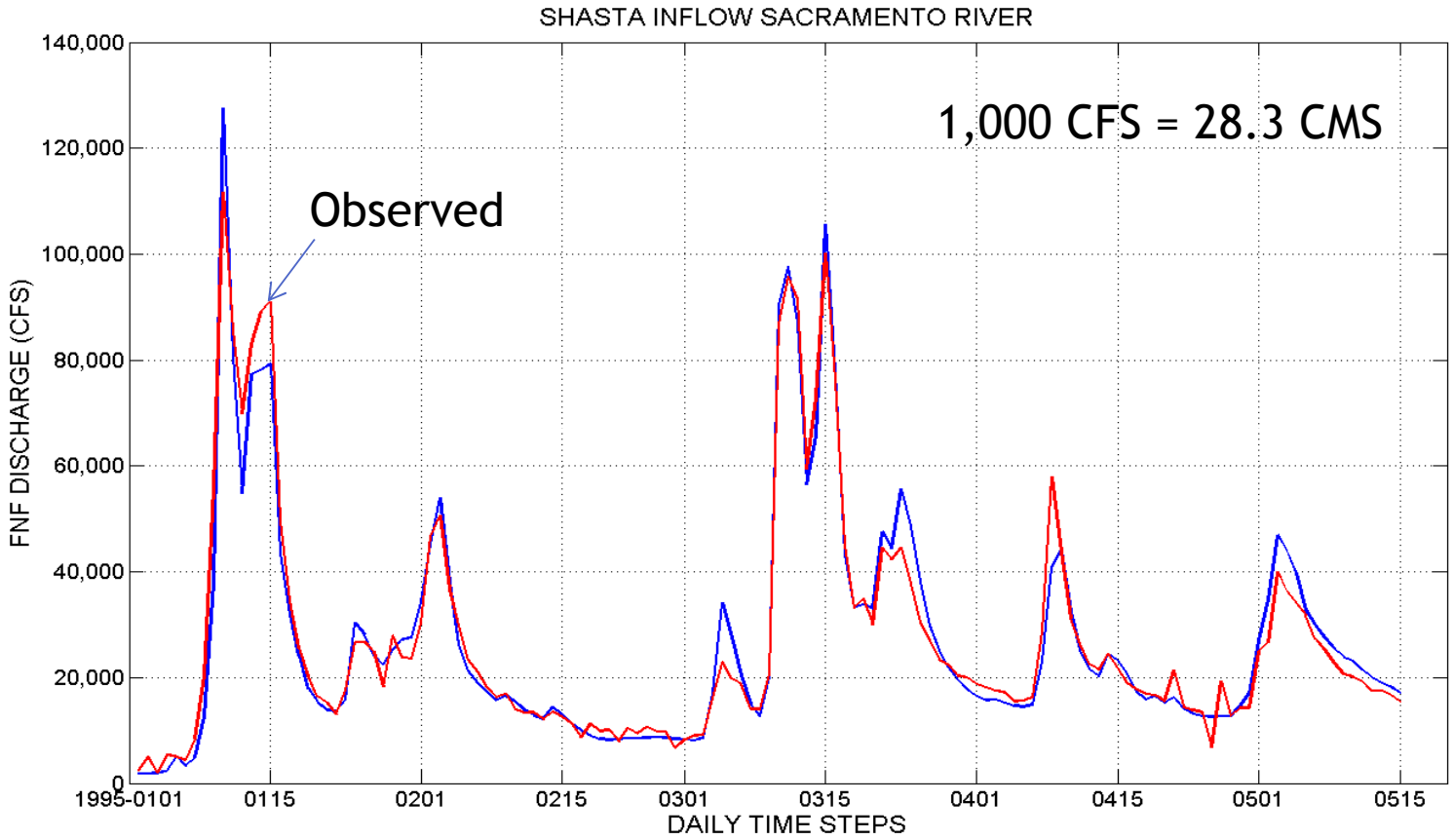
Upper air Observations (Oakland)
Upper air North American Reanalysis Data (Eureka)
(~ 20 years 12 hourly data)

Forecast Component Models (1 – 9 Months)

NCEP(CFS) and CNRFC(NWSRFS&CHPS)



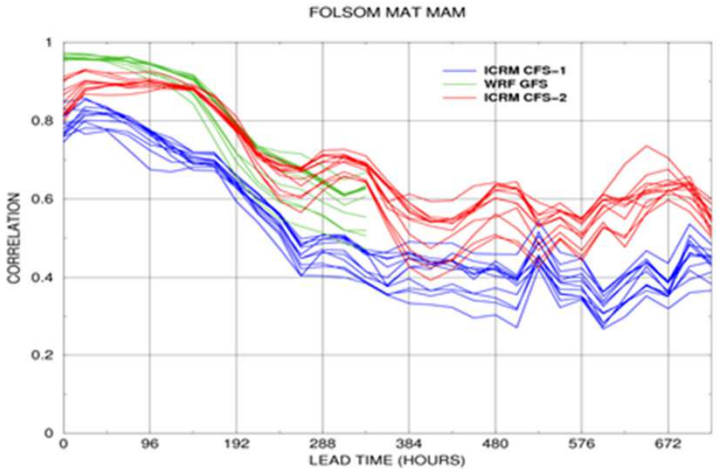
SHASTA 1995 EVENT

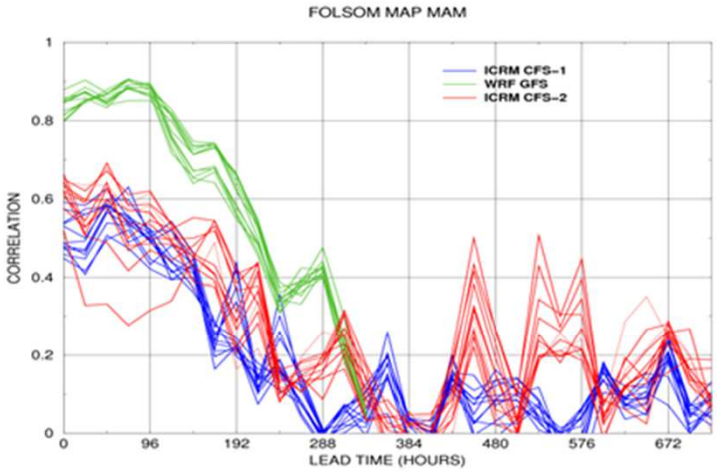


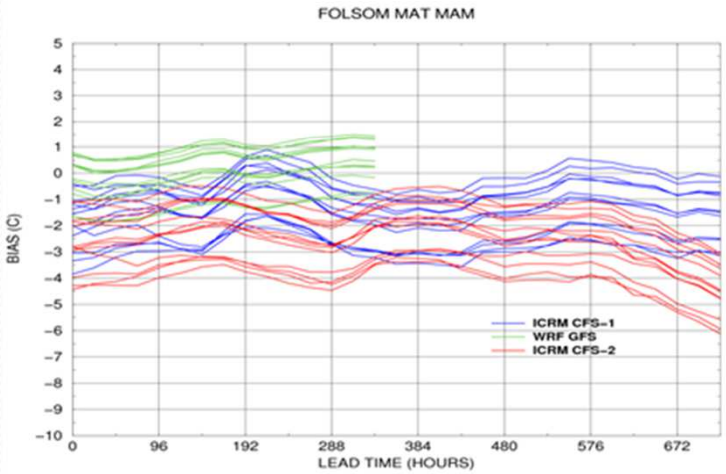
Forecast Evaluation Data

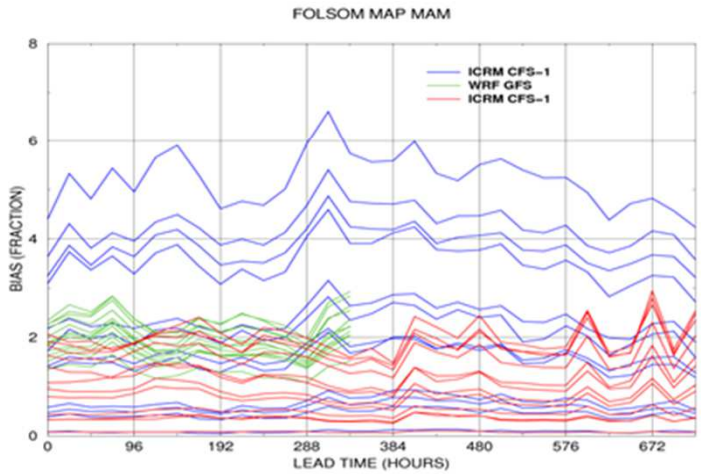
DATA SOURCE	COVERAGE
OBSERVATIONS (MAP and MAT)	06/15/2009 – 11/04/2012
OBSERVATIONS (INFLOW)	01/01/2010 – 01/08/2013
ICRM-CFS1	11/26/2010 – 10/23/2012
WRF	11/07/2011 – 11/02/2012
ICRM-CFS2	02/21/2012 - 11/12/2012

Cross-Correlation and Bias (Folsom)

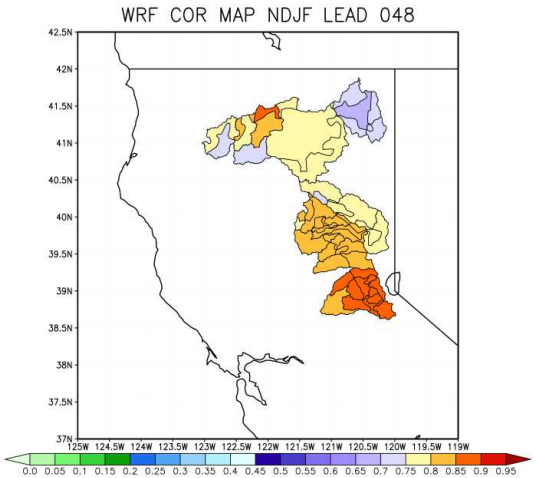


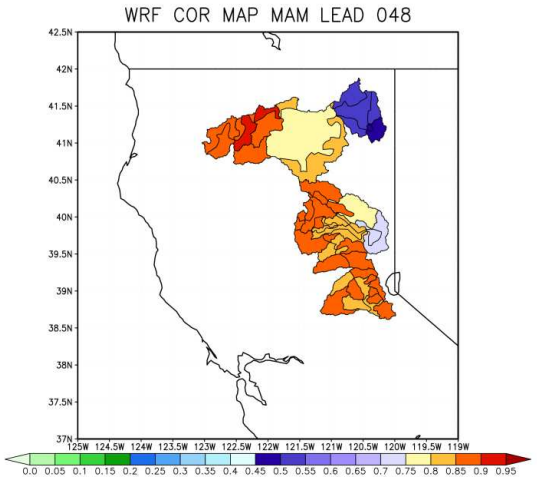


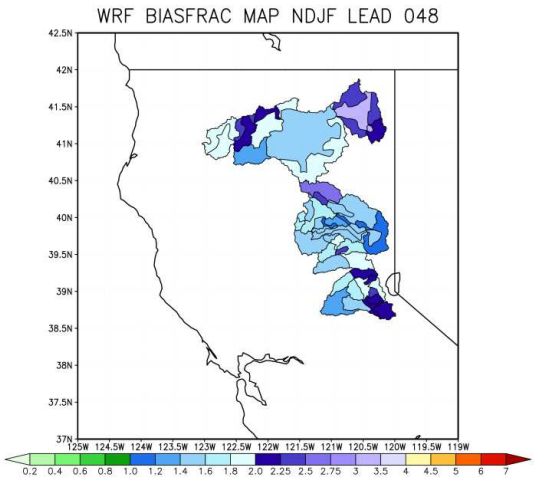


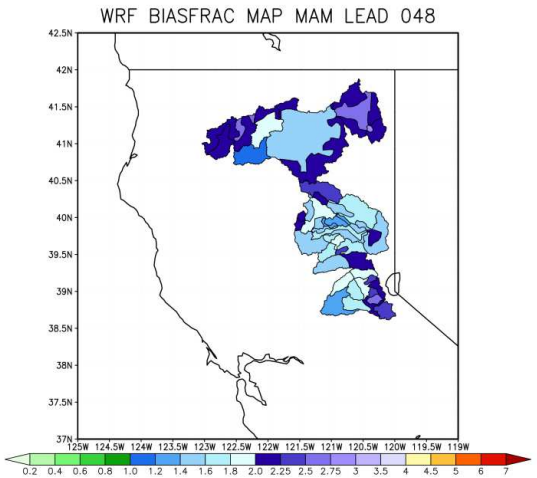


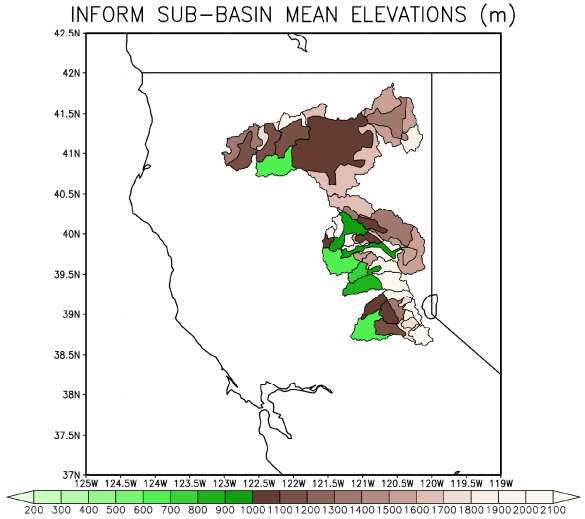
Spatial Distribution of Bias and Correlation



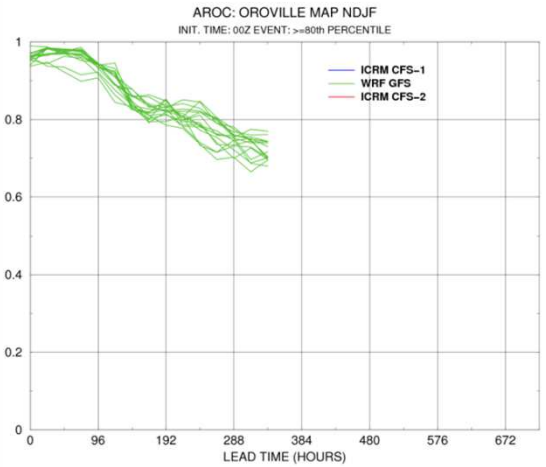


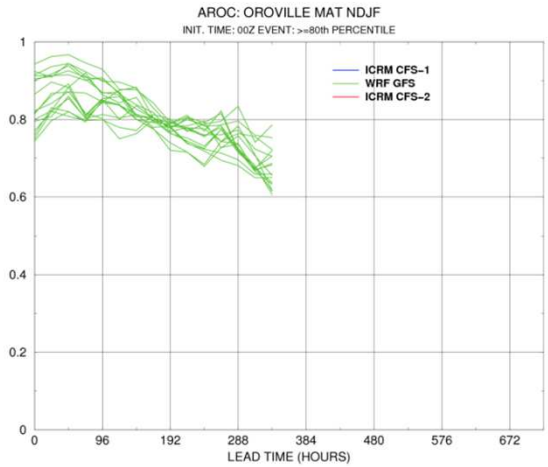


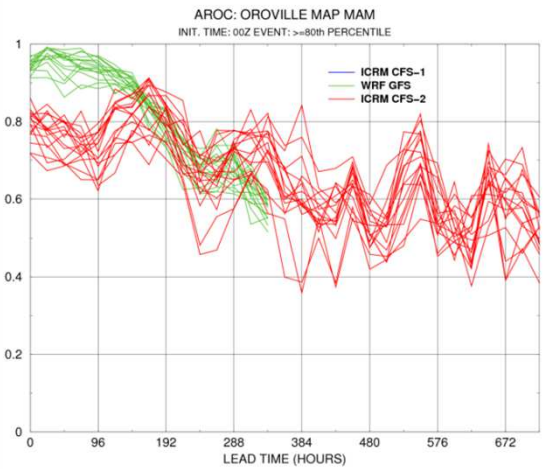


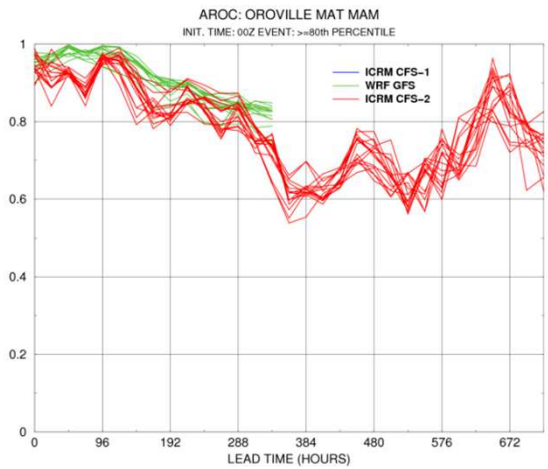


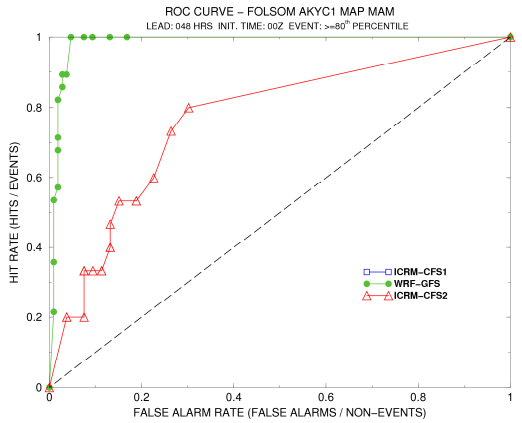
Probabilistic Performance Measures (Oroville)



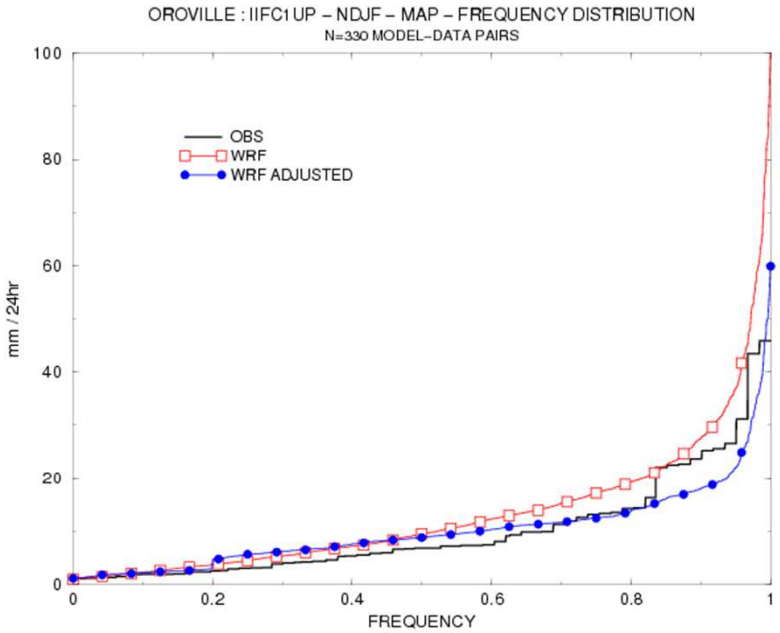


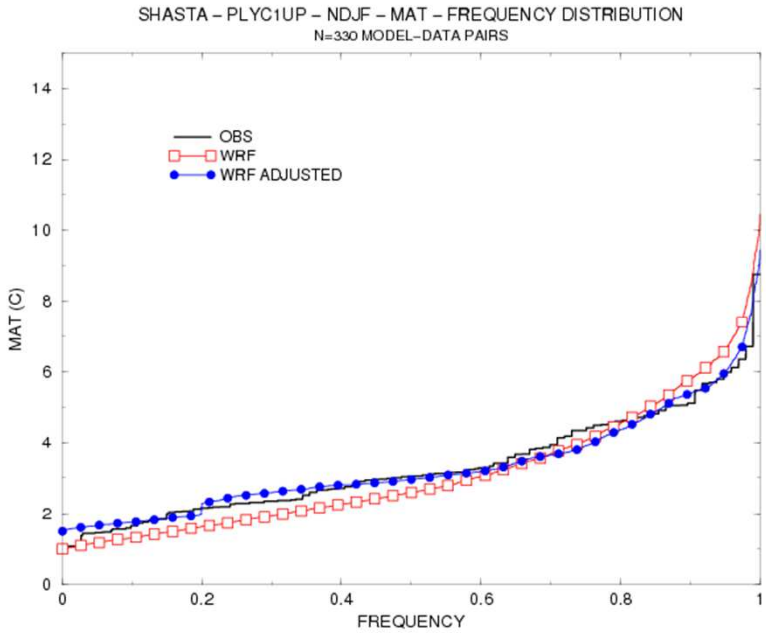






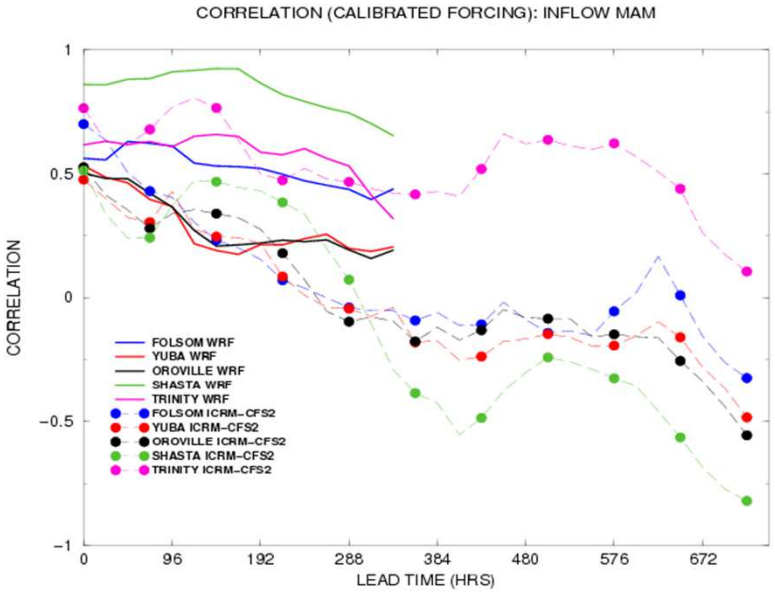
Probabilistic Bias Adjustment MAP/MAT

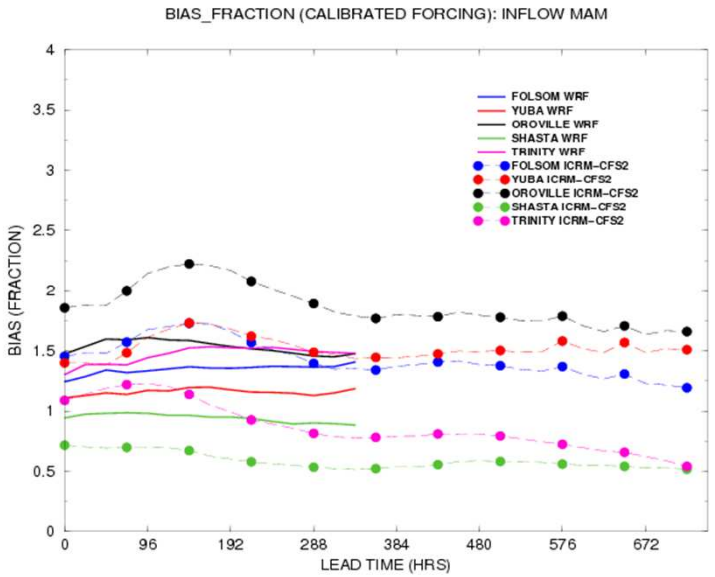


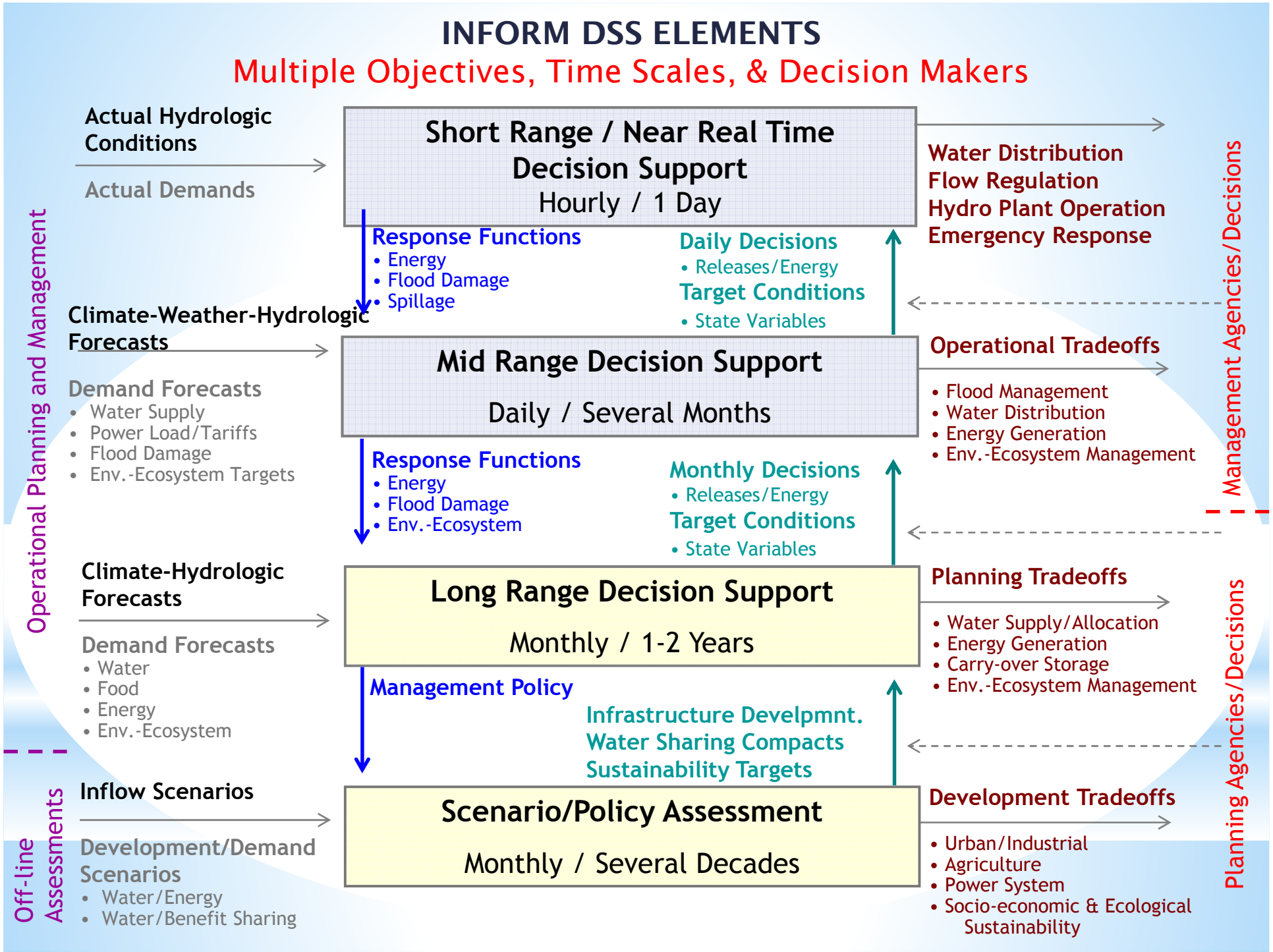


CUMULATIVE FREQUENCY

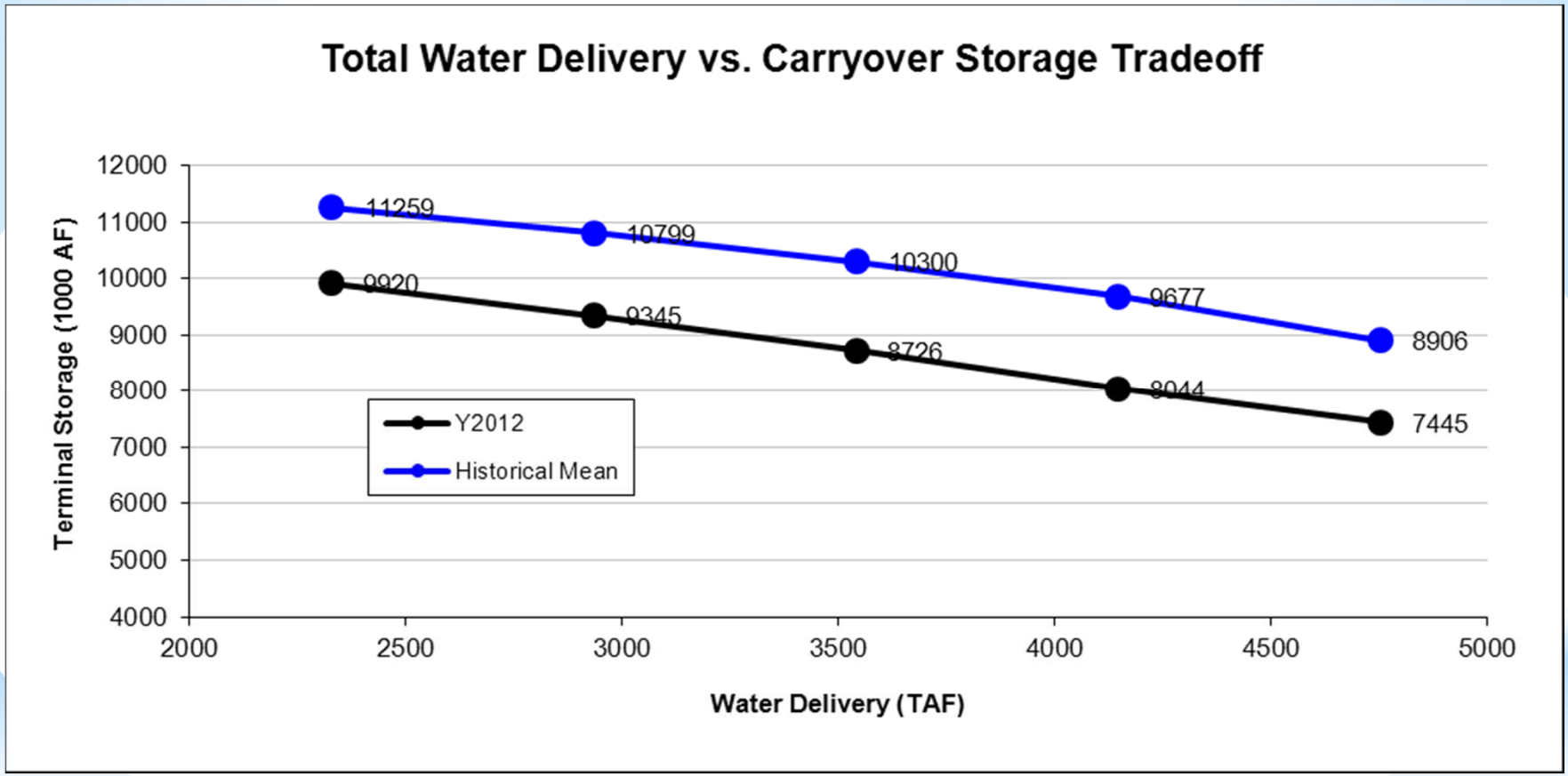
Inflow Forecasts (Adjusted)



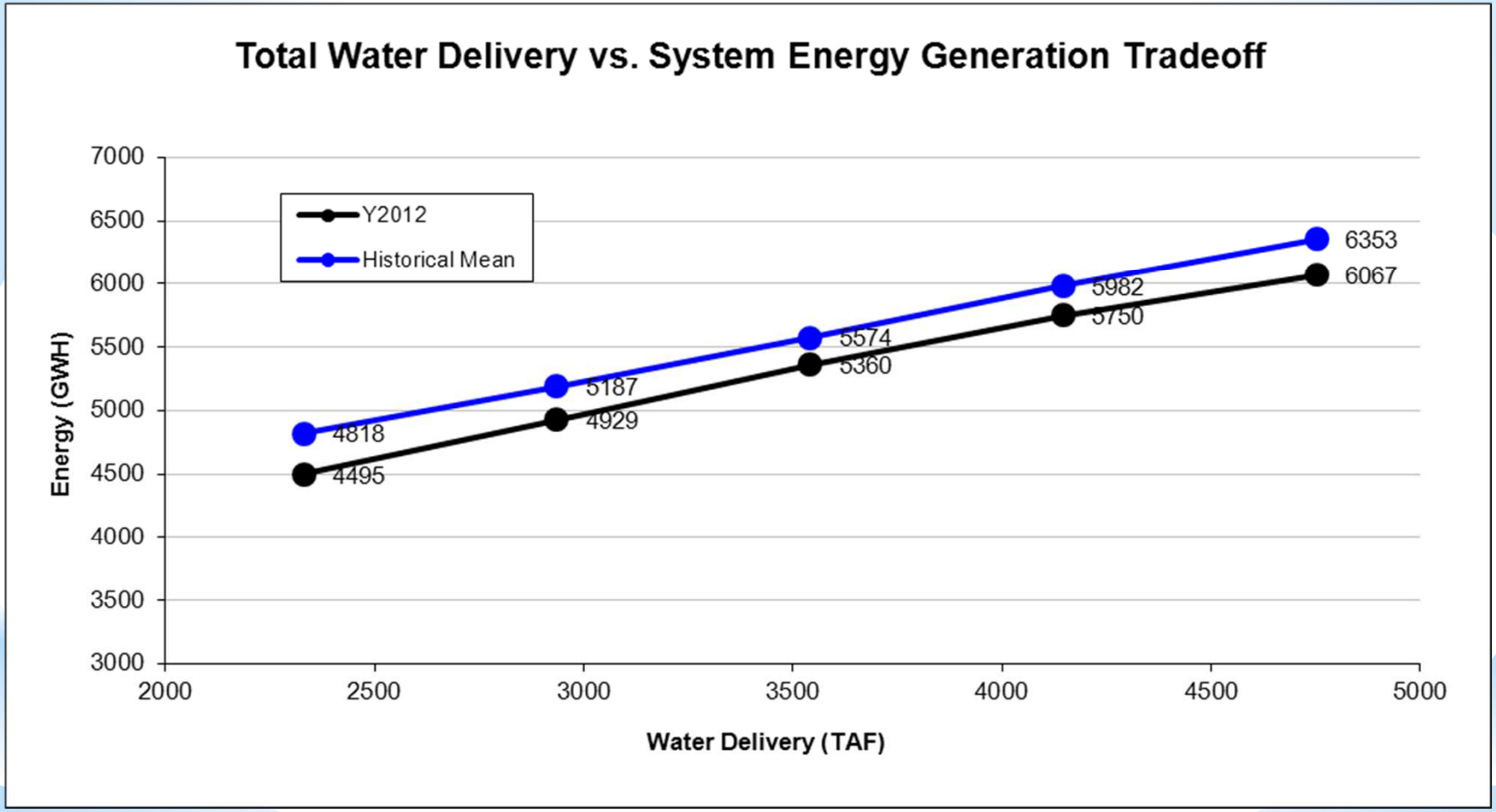



INFORM DSS ELEMENTS
Multiple Objectives, Time Scales, & Decision Makers
Actual Hydrologic Conditions
Actual Demands
Short Range / Near Real Time Decision Support
Hourly / 1 Day
Response Functions
• Energy
• Flood Damage
• Spillage
Daily Decisions
• Releases/Energy
Target Conditions
• State Variables
Water Distribution
Flow Regulation
Hydro Plant Operation
Emergency Response
Climate-Weather-Hydrologic Forecasts
Demand Forecasts
• Water Supply
• Power Load/Tariffs
• Flood Damage
• Env.-Ecosystem Targets
Mid Range Decision Support
Daily / Several Months
Response Functions
• Energy
• Flood Damage
• Env.-Ecosystem
Monthly Decisions
• Releases/Energy
Target Conditions
• State Variables
Operational Tradeoffs
• Flood Management
• Water Distribution
• Energy Generation
• Env.-Ecosystem Management
Climate-Hydrologic Forecasts
Demand Forecasts
• Water
• Food
• Energy
• Env.-Ecosystem
Long Range Decision Support
Monthly / 1-2 Years
Management Policy
Infrastructure Develpmnt.
Water Sharing Compacts
Sustainability Targets
Planning Tradeoffs
• Water Supply/Allocation
• Energy Generation
• Carry-over Storage
• Env.-Ecosystem Management
Inflow Scenarios
Development/Demand Scenarios
• Water/Energy
• Water/Benefit Sharing
Scenario/Policy Assessment
Monthly / Several Decades
Development Tradeoffs
• Urban/Industrial
• Agriculture
• Power System
• Socio-economic & Ecological Sustainability
Operational Planning and Management
Management Agencies/Decisions
Planning Agencies/Decisions
Off-line Assessments

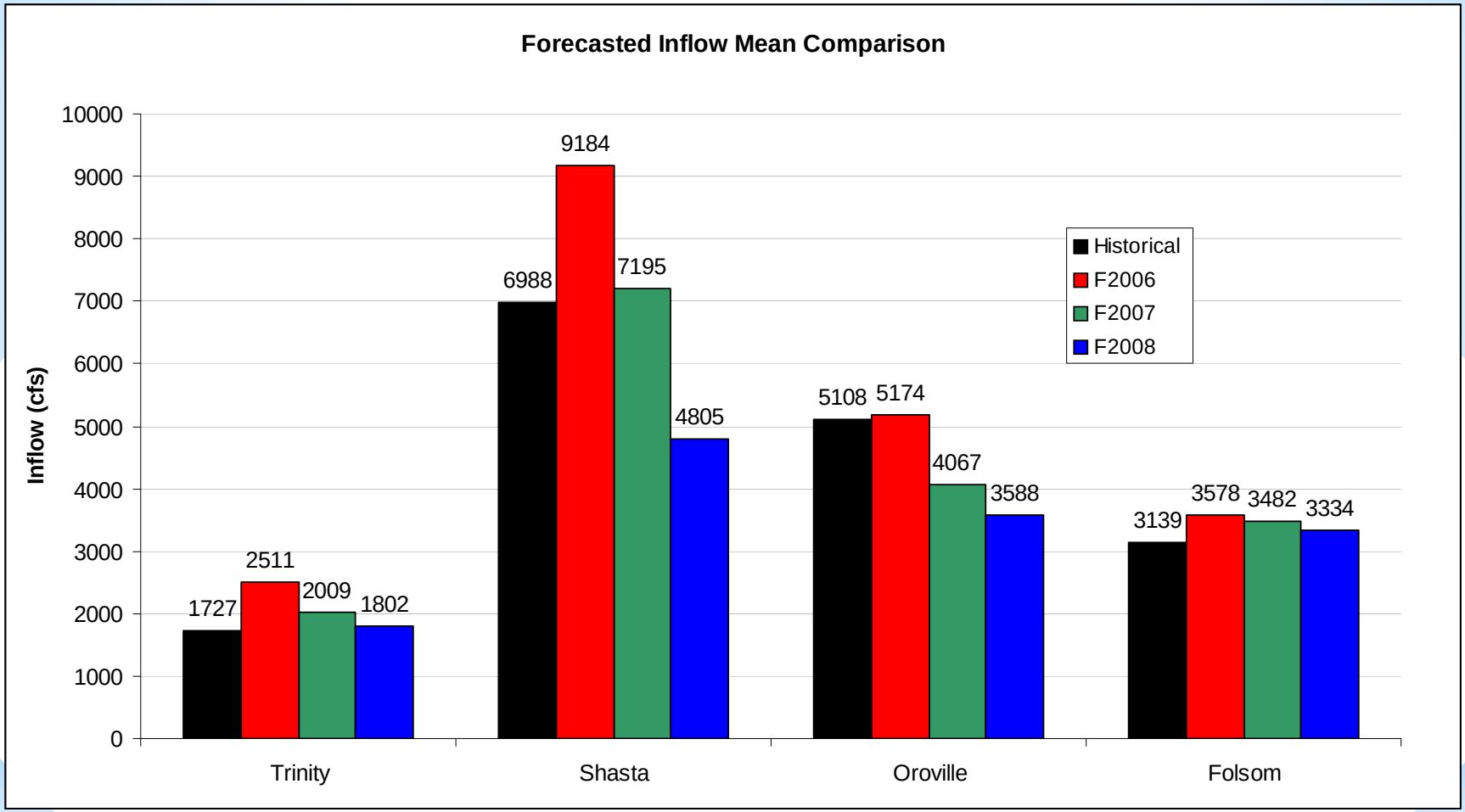
INFORM TRADE-OFFS



INFORM TRADE-OFFS

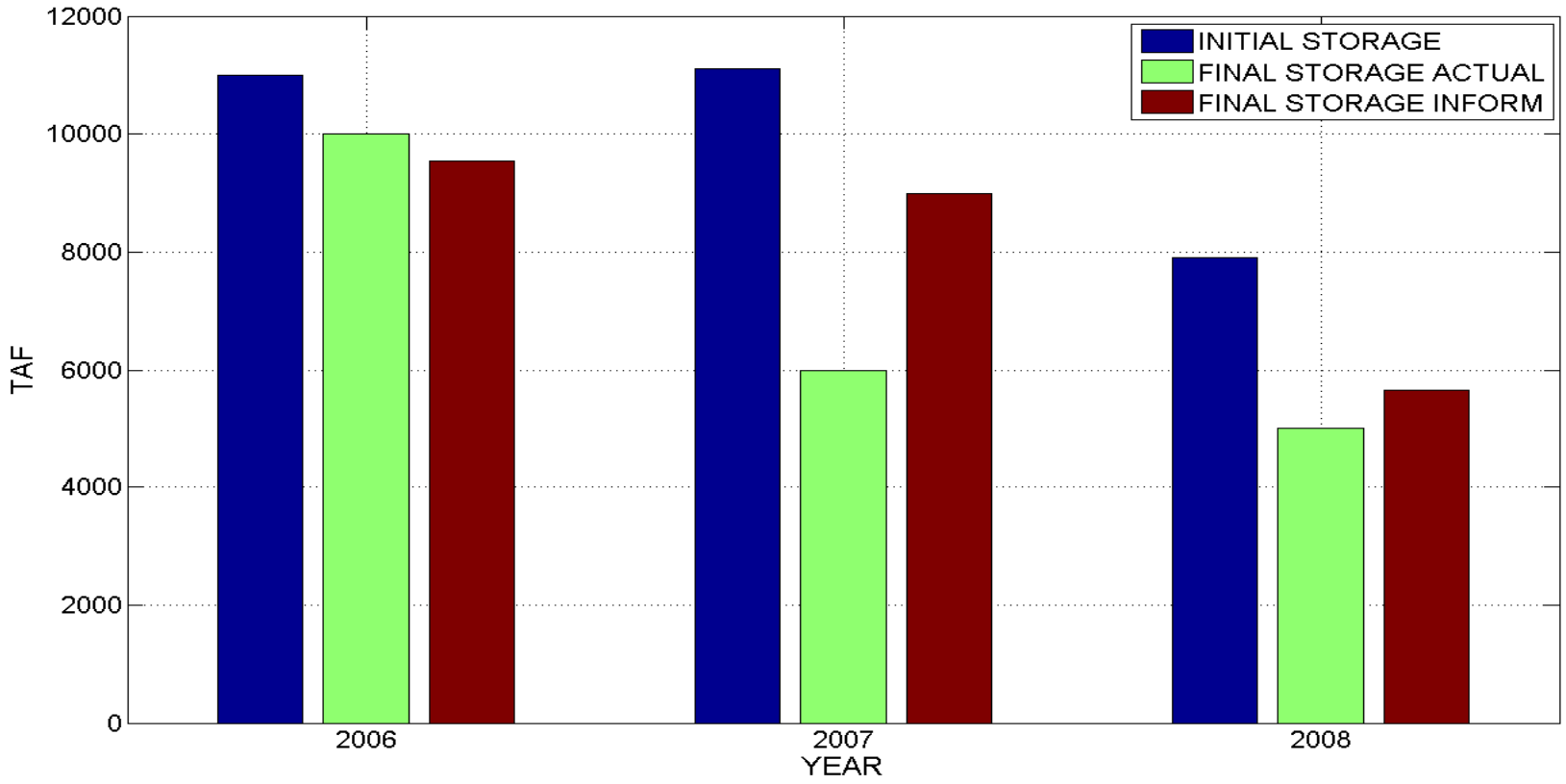


Mean Inflow Forecast Comparison (9 Months)
(2006, 2007, 2008)



2006 (Wet); 2007 (Average); 2008 (Dry)

FORECAST UTILITY DEMONSTRATION



CONCLUSION

Integrated forecast and reservoir management demonstrates significant capability for mitigating water resources impacts of climate and weather variability and uncertainty, **particularly for extremes** (droughts and floods)

ADVANCES
INFORM (2002-2014)

- First prototype demonstration project to support the operational use of climate weather and hydrologic forecasts for operational water resources planning and management in California
- Development of a template for multi agency coordination for adaptive water management under climatic variability and change
  (in conjunction with more detailed simulation systems)
- Framework for continued improvement of operational forecast and management tools

CHALLENGE AND RESPONSE

Challenge:

Institutional issues for using adaptive management in Northern California: Management processes are legally and institutionally vested in traditional procedures and are change resistant

- unintended consequence: constraints the use of key scientific advances (hydroclimatic forecasting, multi-reservoir optimization, uncertainty characterization, and integrated water resources management)

Response:

INFORM approach is designed to support a truly coordinated, interactive, and adaptive decision process that consistently reconciles long-, mid-, and short-term operational objectives and decisions

- institutional and legal processes establish the framework, broad objectives, and criteria for shared water management rather than policy specifics
- with agency coordination, the adaptive risk-based INFORM approach may become institutional practice as a real time screening and planning tool for identifying beneficial release policies

Thank You

http://www.hrc-lab.org

INFORM Contributing Scientists/Engineers

HRC

K.P. Georgakakos, PI, Hydroclimatology

N.E. Graham, Co-PI, Climate Science & Prediction

T.M. Carpenter, Hydrometeorological Forecasting

M. Murphy, J. Wang, and F.-Y. Cheng, Mesoscale Meteorological Modeling

E. Shamir, Hydrologic Modeling

C. Spencer and J. Sperfslage, Computer Science

GWRI

A.P. Georgakakos, Co-PI, Decision Science

Huaming Yao, Hydropower

Martin Kistenmacher, Uncertainty Mgt

Dongha Kim, Routing/Temperature Models