Lake Mendocino
Forecast-Informed Reservoir Operations

F. Martin Ralph
Center for Western Weather and Water Extremes
UC San Diego/Scripps Institution of Oceanography

California Extreme Precipitation Symposium
Sacramento, CA, 6 September 2016,

Ackowledgements to Jay Jasperse and the FIRO Steering Committee

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

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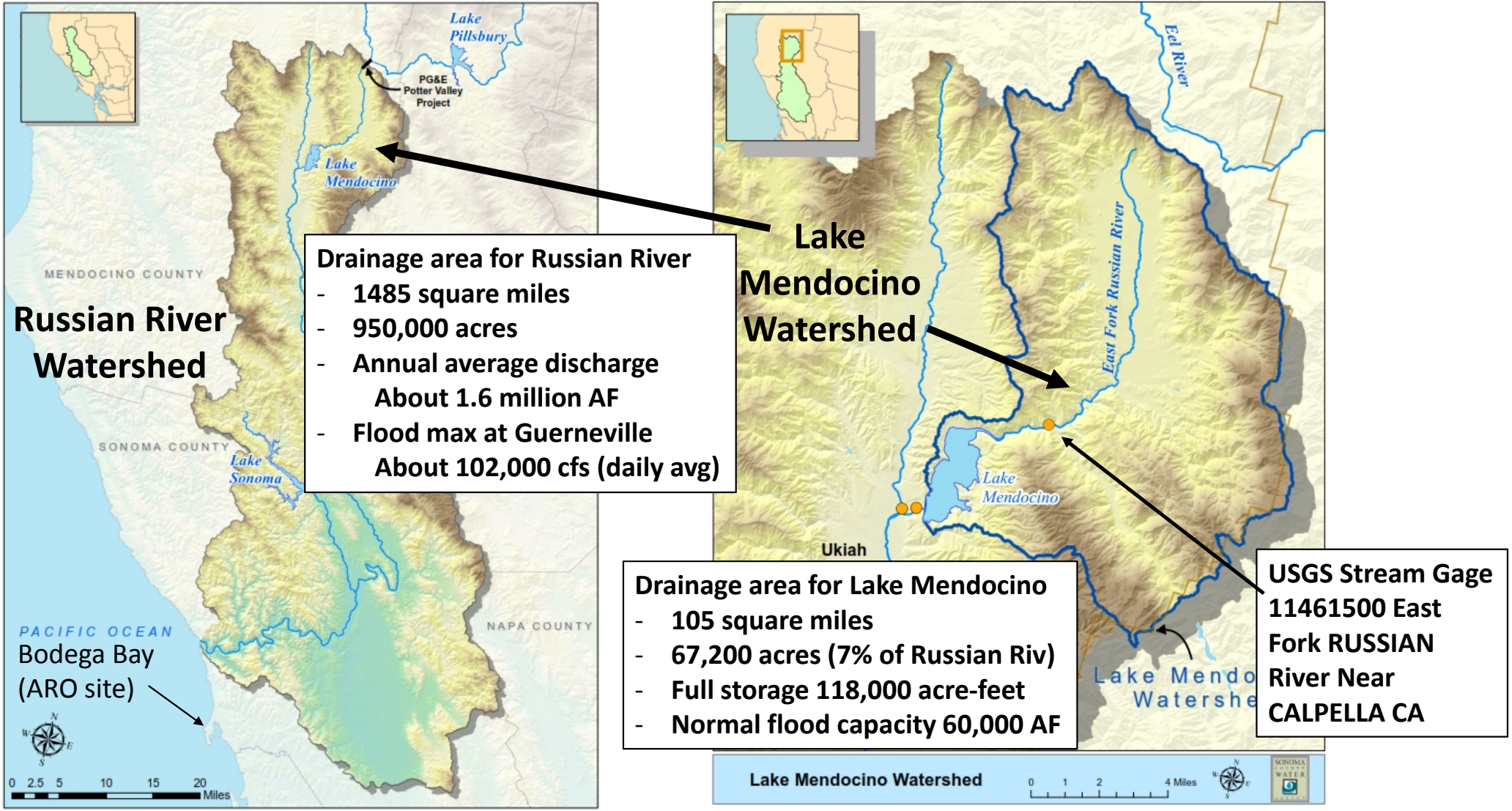
UCSD

Context

Locations of the Russian River and Lake Mendocino


Lake Pillsbury
PG&E Potter Valley Project
Lake Mendocino
MENDOCINO COUNTY
Russian River Watershed
SONOMA COUNTY
Lake Sonoma
NAPA COUNTY
PACIFIC OCEAN
Bodega Bay (ARO site)
0 2.5 5 10 15 20 Miles
Drainage area for Russian River
- 1485 square miles
- 950,000 acres
- Annual average discharge
About 1.6 million AF
- Flood max at Guerneville
About 102,000 cfs (daily avg)
Lake Mendocino Watershed
Eel River
East Fork Russian River
Lake Mendocino
Ukiah
Drainage area for Lake Mendocino
- 105 square miles
- 67,200 acres (7% of Russian Riv)
- Full storage 118,000 acre-feet
- Normal flood capacity 60,000 AF
USGS Stream Gage 11461500 East Fork RUSSIAN River Near CALPELLA CA
Lake Mendocino Watershed
0 1 2 4 Miles

Lake Mendocino in Sonoma County – Drought July 2014

Lake Mendocino, July 2014

Russian River in Sonoma County – Flood February 2014

Flood control operations: **US Army Corps of Engineers**

Water Supply operations: **Sonoma County Water Agency**

Fisheries Restoration: **NOAA**

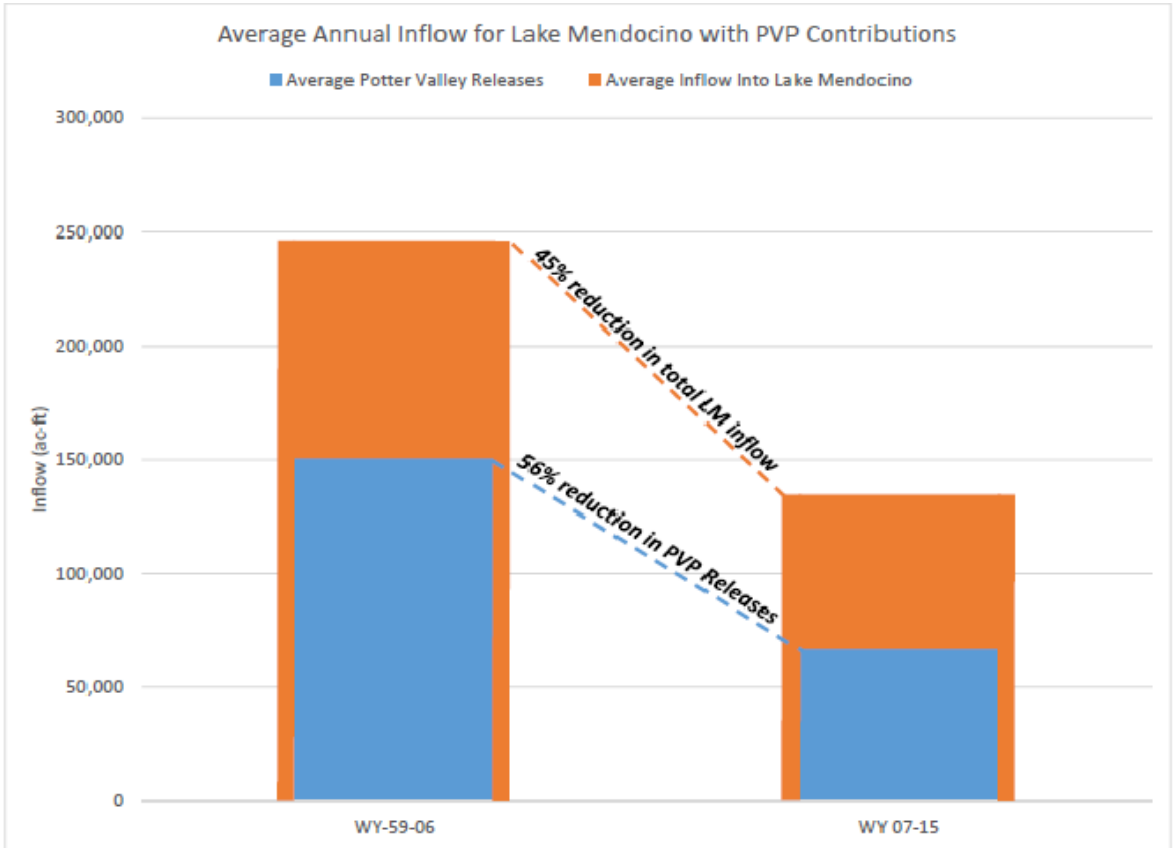
Russian River near Monte Rio, 9 Feb 2014 *(M. Ralph)*

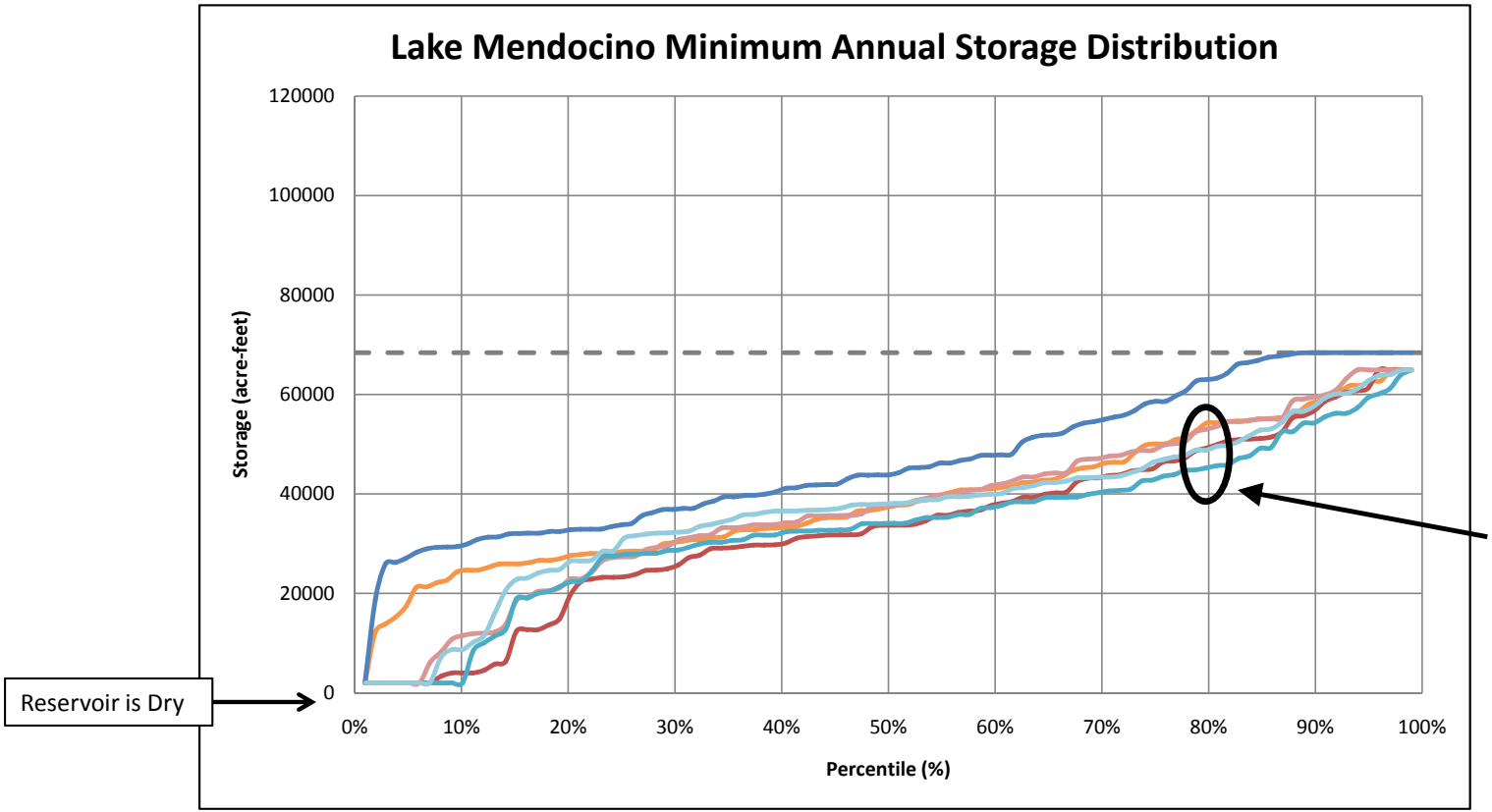
The Issue: Lake Mendocino's Water Supply Is Not Reliable

Some Reasons For Low Water Supply Reliability:

- Relatively small storage capacity
- Relatively unproductive watershed
- Reduced inflow from Potter Valley Project (Eel River)
- Highly variable precipitation patterns
  - Almost 50% rainfall from atmospheric rivers
- Future growth & climate change will likely further reduce reliability

Reduced Inflows From Potter Valley Have Significant Impacts on Lake Mendocino





Scenario #1: Modeled Data (1910 - 2013) with Current Operations of PVP, 2015 Projected Demands, and Modeled Historical Climate

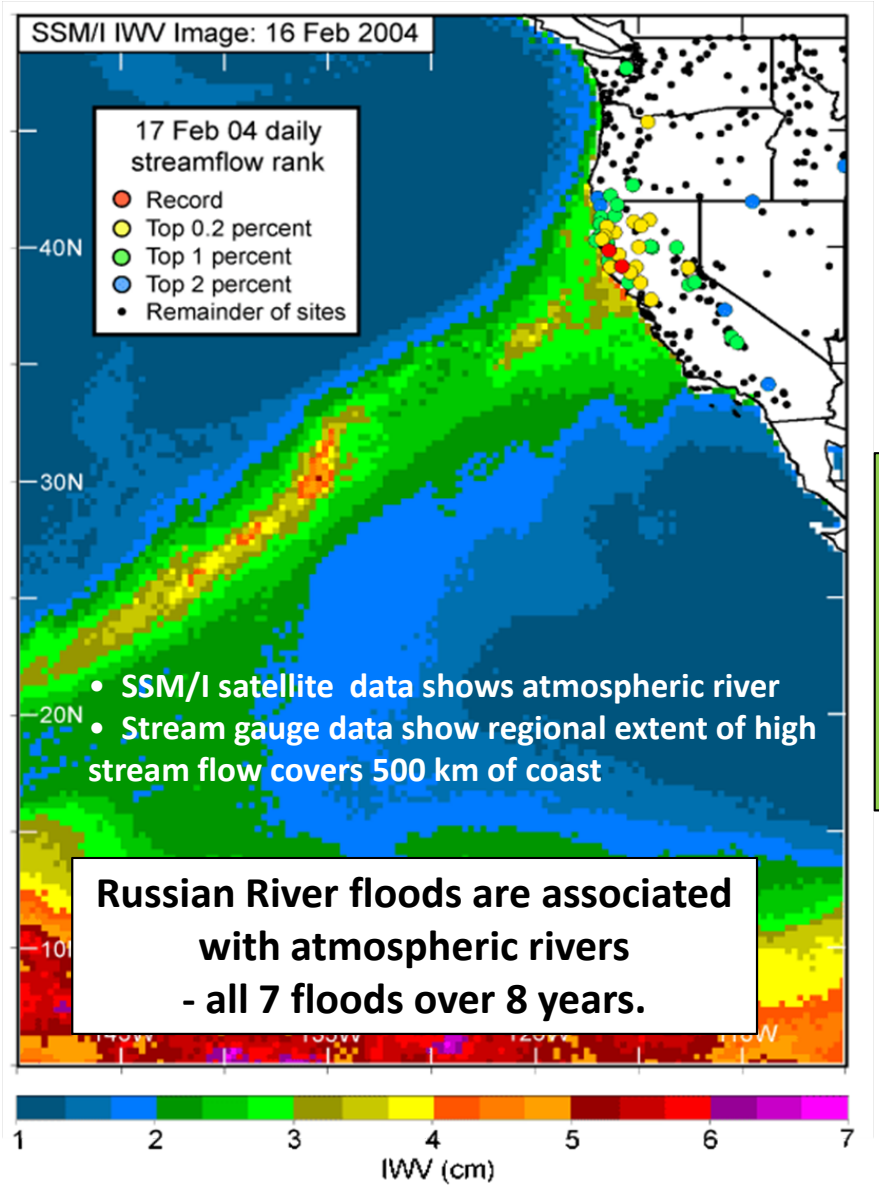
Scenario #4: Modeled Data (1910 - 2013) with Current Operations of PVP, 2045 Projected High Demands, and Modeled Historical Climate

Scenario #5: Modeled Data (2001 - 2099) with Current Operations of PVP, 2045 Projected Low Demands, and Modeled Dry Climate

Scenario #6: Modeled Data (2001 - 2099) with Current Operations of PVP, 2045 Projected High Demands, and Modeled Dry Climate

Scenario #7: Modeled Data (2001 - 2099) with Current Operations of PVP, 2045 Projected Low Demands, and Modeled Wet Climate

Scenario #8: Modeled Data (2001 - 2099) with Current Operations of PVP, 2045 Projected High Demands, and Modeled Wet Climate



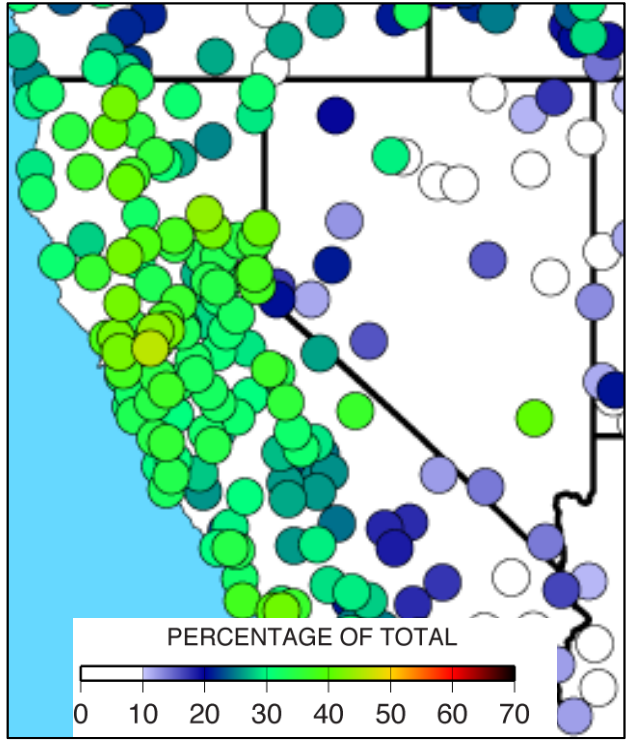
Flooding on California's Russian River: Role of atmospheric rivers

Ralph, F.M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, A. White (*Geophys. Res. Lett., 2006)*

ARs can CAUSE FLOODS and PROVIDE WATER SUPPLY

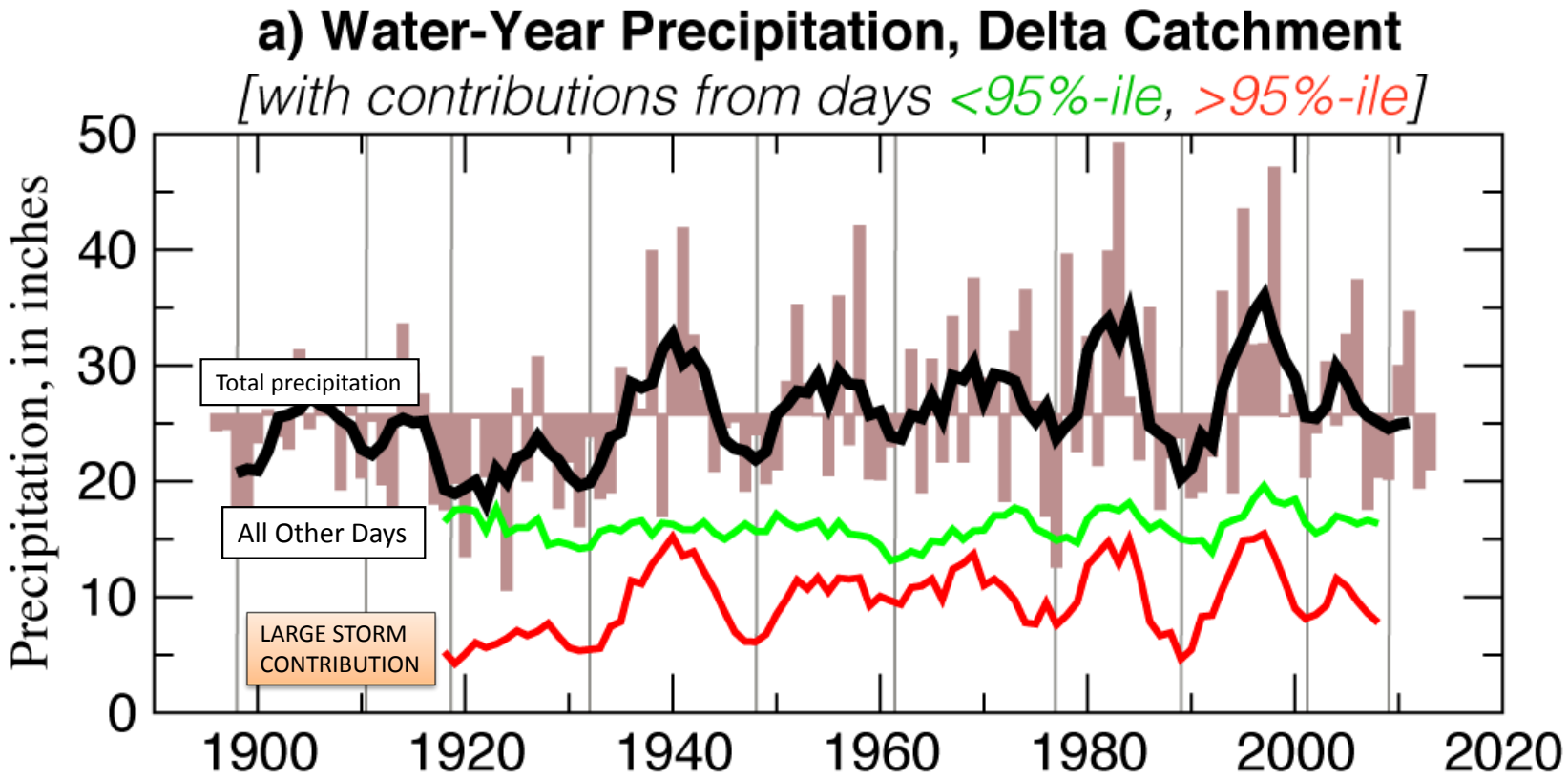
Atmospheric Rivers, Floods and the Water Resources of California

Mike Dettinger, M. Ralph, , T. Das, P. Neiman, D. Cayan *(Water, 2011*)

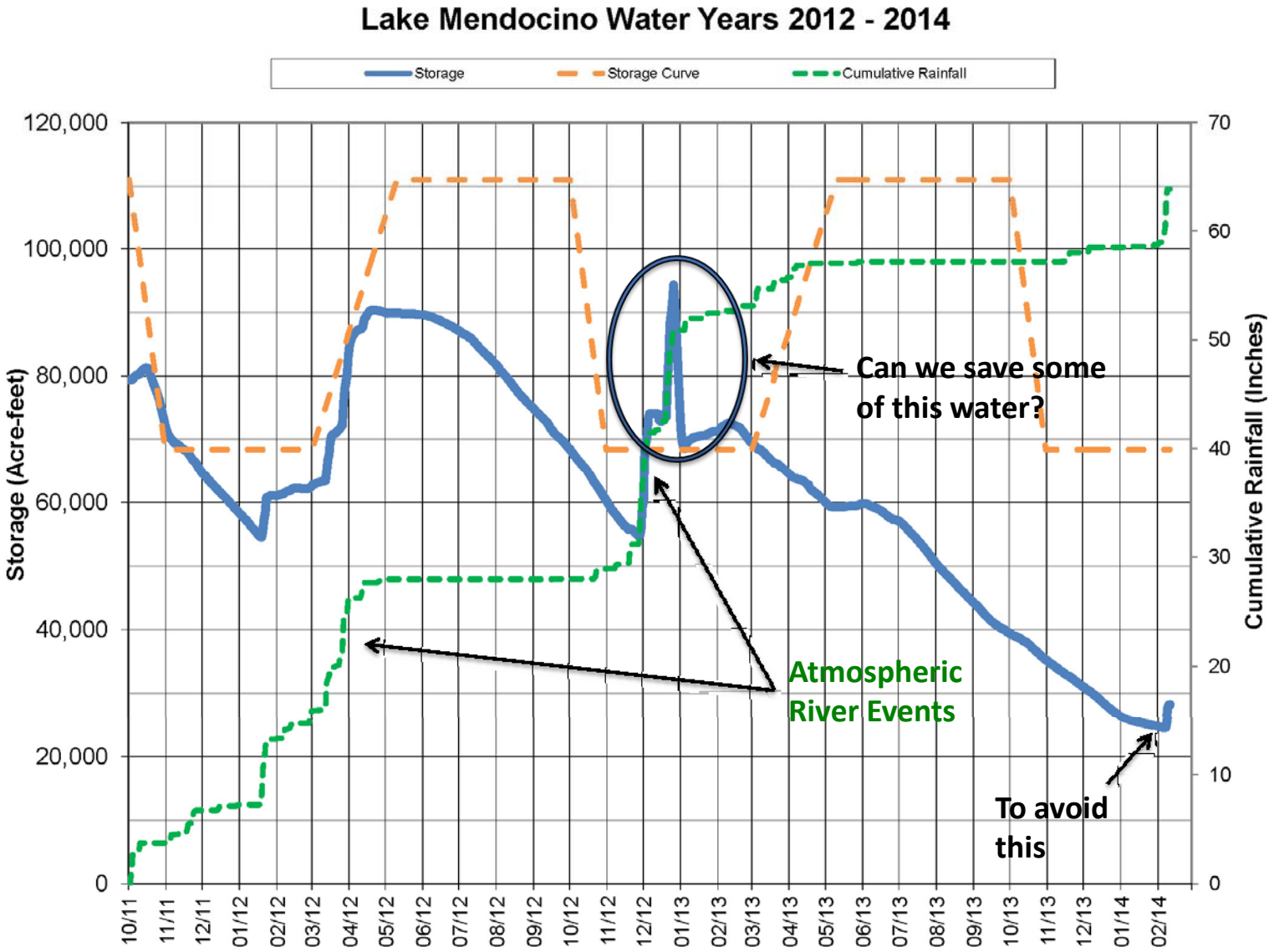


A few large storms (or their absence)

account for a disproportionate amount of California's precipitation variability



Dettinger and Cayan **Drought and the Delta—A Matter of Extremes**
San Francisco Estuary and Watershed Science, April 2014


Lake Mendocino Water Years 2012 - 2014
Storage
Storage Curve
Cumulative Rainfall
Storage (Acre-feet)
Cumulative Rainfall (Inches)
120,000
100,000
80,000
60,000
40,000
20,000
0
70
60
50
40
30
20
10
0
10/11
11/11
12/11
01/12
02/12
03/12
04/12
05/12
06/12
07/12
08/12
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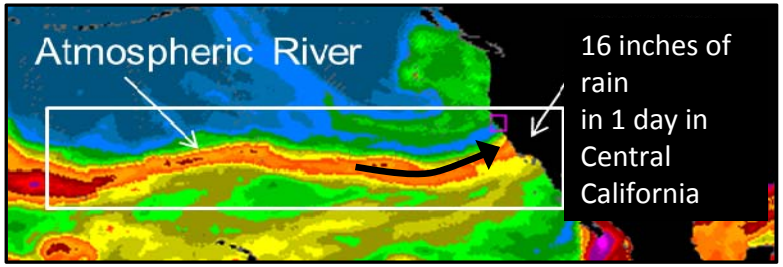
11/12
12/12
01/13
02/13
03/13
04/13
05/13
06/13
07/13
08/13
09/13
10/13
11/13
12/13
01/14
02/14
Can we save some of this water?
Atmospheric River Events
To avoid this

The FIRO Steering Committee and Strategies

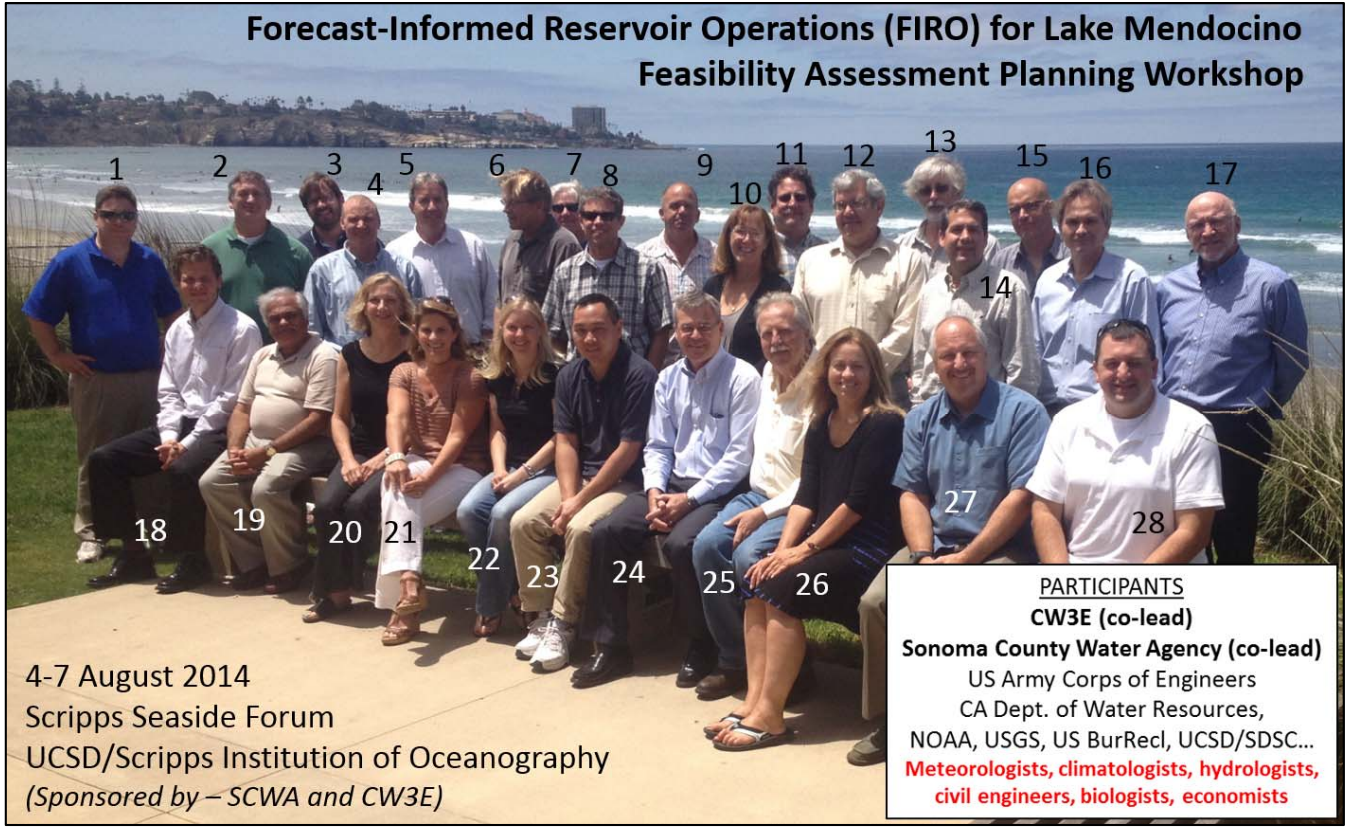


Forecast-Informed Reservoir Operations*: A Concept Supporting Water Security, Flood Control, Ecosystems

FIRO Steering Committee:
Co-Chairs Jasperse & Ralph

Local, State, Federal and University weather and water experts working to evaluate the potential viability of using forecasts of atmospheric rivers, rain and streamflow to enable safe retention of extra water if major storms are not predicted over the watershed in the coming days, or to enhance flood control if strong storms *are* predicted.

***http://cw3e.ucsd.edu/FIRO/**



FACT SHEET: Lake Mendocino Forecast Informed Reservoir Operations
Preliminary Viability Assessment Work Plan

PURPOSE: The Lake Mendocino Forecast Informed Reservoir Operations (FIRO) Preliminary Viability Assessment Work Plan (Work Plan) describes an approach for using modeling, forecasting tools and improved information to determine whether the Lake Mendocino Water Control Manual can be adjusted to improve flood-control and water supply operations. This proof-of-concept FIRO viability assessment uses Lake Mendocino as a model that could have applicability to other reservoirs.

*STEERING COMMITTEE CO-CHAIRS

Jay Jasperse
Sonoma County Water Agency

F. Martin Ralph
Center for Western Weather and Water Extremes at Scripps Institute of Oceanography

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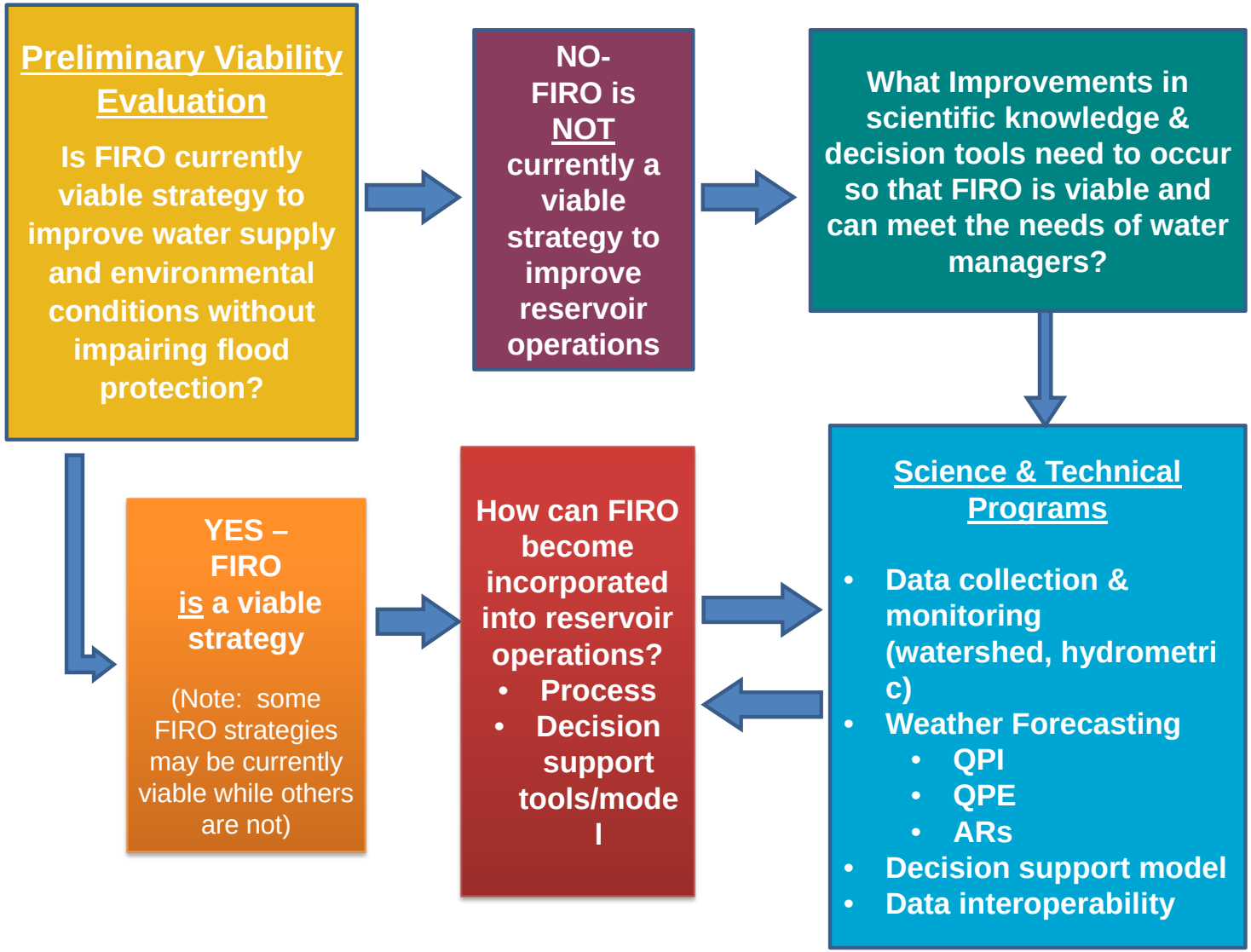
David Ford
David Ford Consulting Engineers

Arleen O'Donnell
Eastern Resarch Group

Ann DuBay
Sonoma County Water Agency

September 2015


Preliminary Viability Evaluation
Is FIRO currently viable strategy to improve water supply and environmental conditions without impairing flood protection?
NO- FIRO is NOT currently a viable strategy to improve reservoir operations
What Improvements in scientific knowledge & decision tools need to occur so that FIRO is viable and can meet the needs of water managers?
YES – FIRO is a viable strategy
(Note: some FIRO strategies may be currently viable while others are not)
How can FIRO become incorporated into reservoir operations?
• Process
• Decision support tools/model
Science & Technical Programs
• Data collection & monitoring (watershed, hydrometric)
• Weather Forecasting
• QPI
• QPE
• ARs
• Decision support model
• Data interoperability

Demonstration Project Status

Steering Committee Goals

- Create a plan to assess the potential viability of FIRO at Lake Mendocino
- Carry out the work plan with a core interagency team inclusive of the reservoirs operators, stakeholders and scientists

Communication

- Monthly calls
- Quarterly meetings

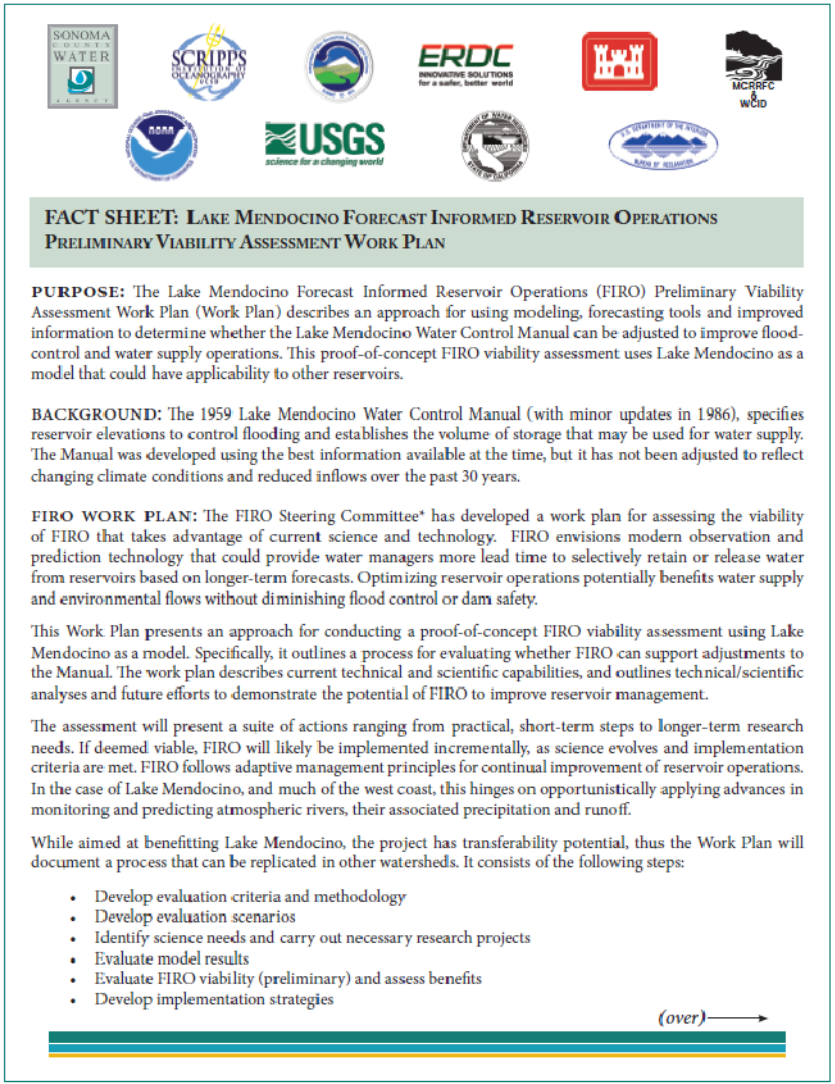
Annual Workshops

- Three workshops to date (2014, 2015, 2016)

5-year FIRO Work Plan Finalized Sept. 2015

Three "Task Groups" Are Carrying Out the Workplan

- **Preliminary Viability Assessment (end of year)**
- Procedural Matters & Implementation
- Science



FACT SHEET: LAKE MENDOCINO FORECAST INFORMED RESERVOIR OPERATIONS PRELIMINARY VIABILITY ASSESSMENT WORK PLAN

PURPOSE: The Lake Mendocino Forecast Informed Reservoir Operations (FIRO) Preliminary Viability Assessment Work Plan (Work Plan) describes an approach for using modeling, forecasting tools and improved information to determine whether the Lake Mendocino Water Control Manual can be adjusted to improve flood-control and water supply operations. This proof-of-concept FIRO viability assessment uses Lake Mendocino as a model that could have applicability to other reservoirs.

BACKGROUND: The 1959 Lake Mendocino Water Control Manual (with minor updates in 1986), specifies reservoir elevations to control flooding and establishes the volume of storage that may be used for water supply. The Manual was developed using the best information available at the time, but it has not been adjusted to reflect changing climate conditions and reduced inflows over the past 30 years.

FIRO WORK PLAN: The FIRO Steering Committee* has developed a work plan for assessing the viability of FIRO that takes advantage of current science and technology. FIRO envisions modern observation and prediction technology that could provide water managers more lead time to selectively retain or release water from reservoirs based on longer-term forecasts. Optimizing reservoir operations potentially benefits water supply and environmental flows without diminishing flood control or dam safety.

This Work Plan presents an approach for conducting a proof-of-concept FIRO viability assessment using Lake Mendocino as a model. Specifically, it outlines a process for evaluating whether FIRO can support adjustments to the Manual. The work plan describes current technical and scientific capabilities, and outlines technical/scientific analyses and future efforts to demonstrate the potential of FIRO to improve reservoir management.

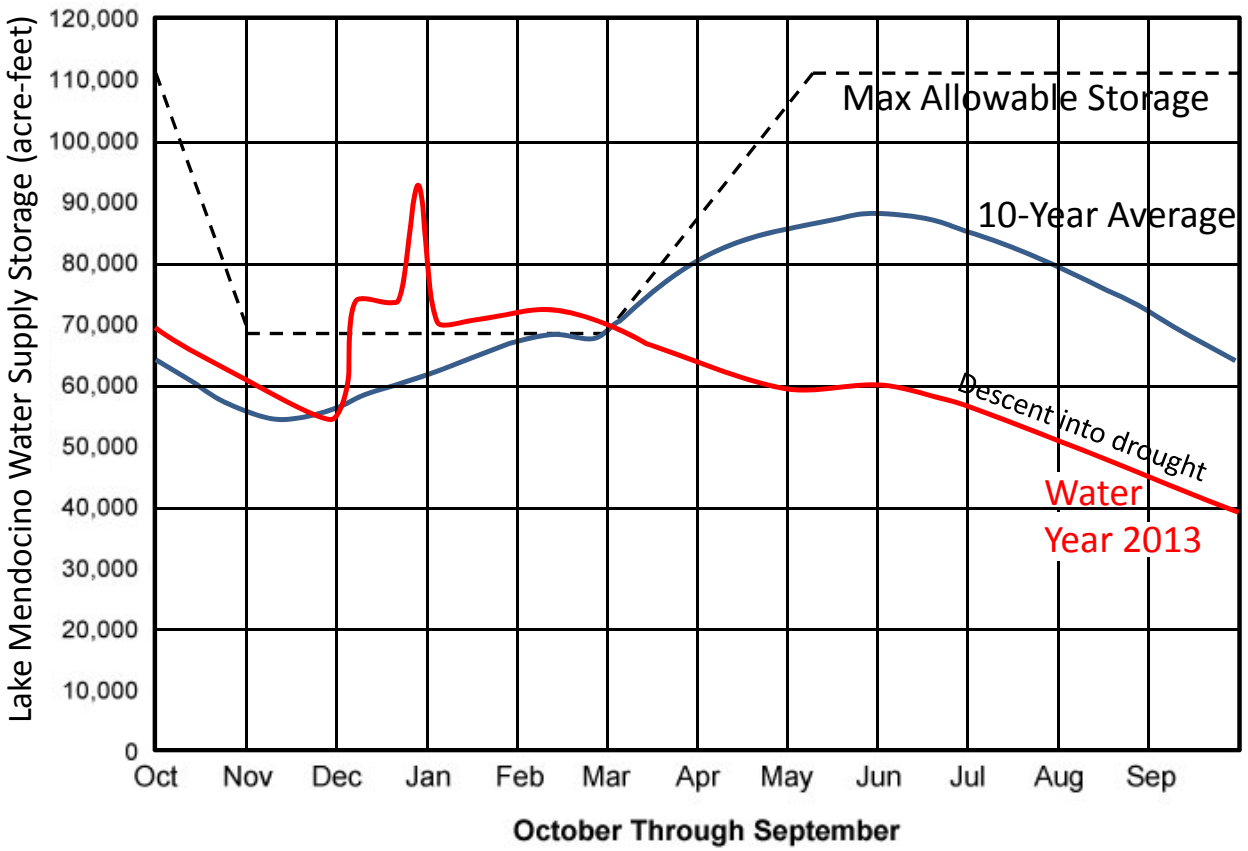
The assessment will present a suite of actions ranging from practical, short-term steps to longer-term research needs. If deemed viable, FIRO will likely be implemented incrementally, as science evolves and implementation criteria are met. FIRO follows adaptive management principles for continual improvement of reservoir operations. In the case of Lake Mendocino, and much of the west coast, this hinges on opportunistically applying advances in monitoring and predicting atmospheric rivers, their associated precipitation and runoff.

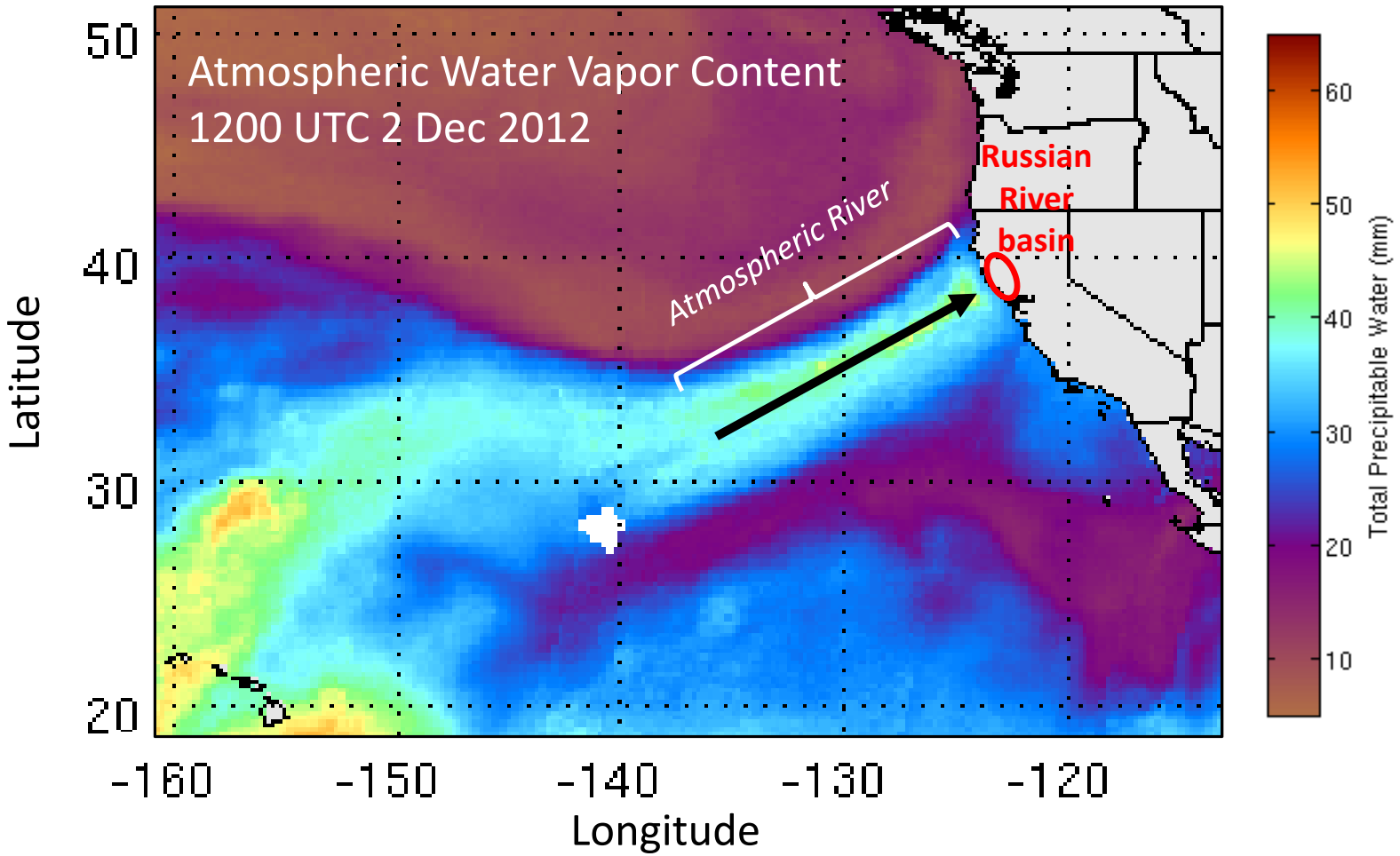
While aimed at benefitting Lake Mendocino, the project has transferability potential, thus the Work Plan will document a process that can be replicated in other watersheds. It consists of the following steps:

- Develop evaluation criteria and methodology
- Develop evaluation scenarios
- Identify science needs and carry out necessary research projects
- Evaluate model results
- Evaluate FIRO viability (preliminary) and assess benefits
- Develop implementation strategies

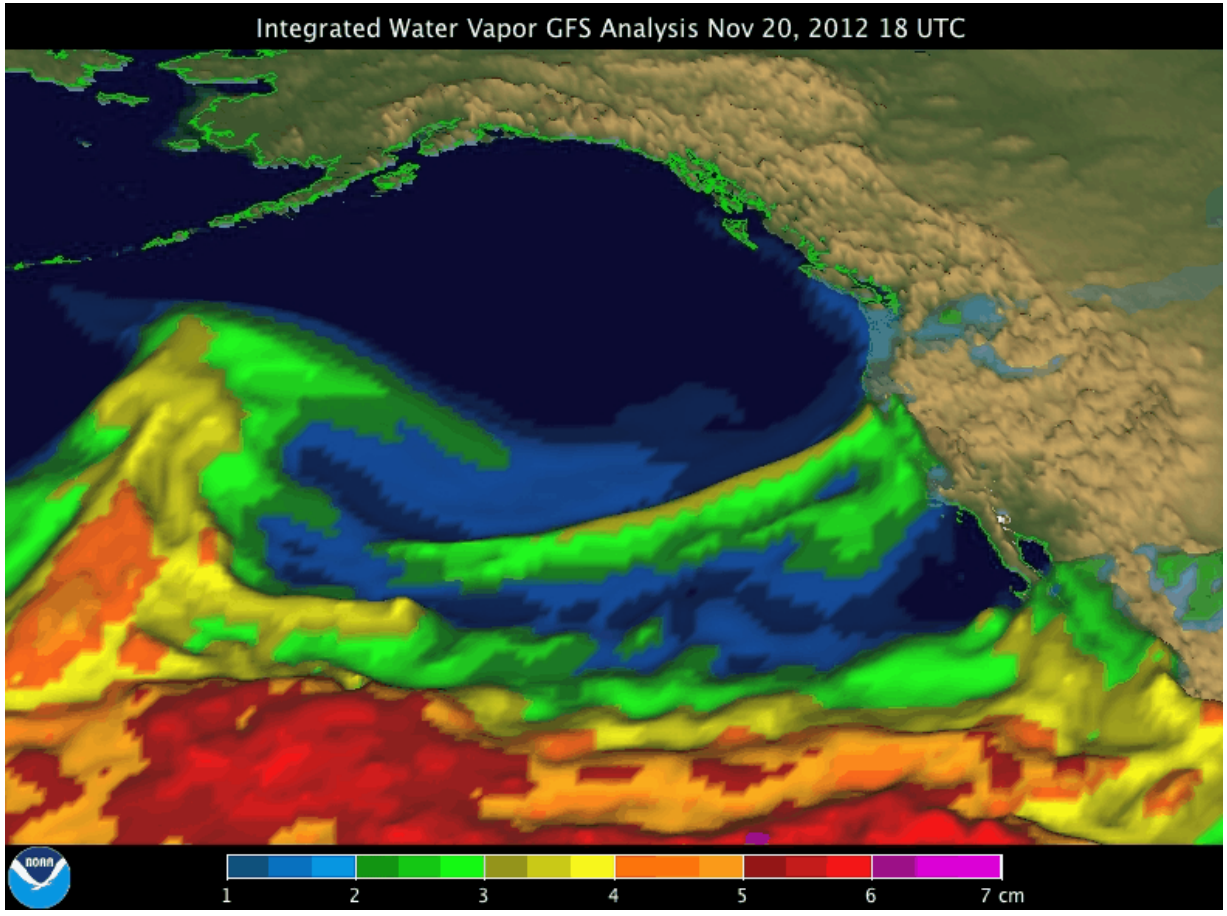
(over)

Lake Mendocino Forecast-Informed Reservoir Operations Concept



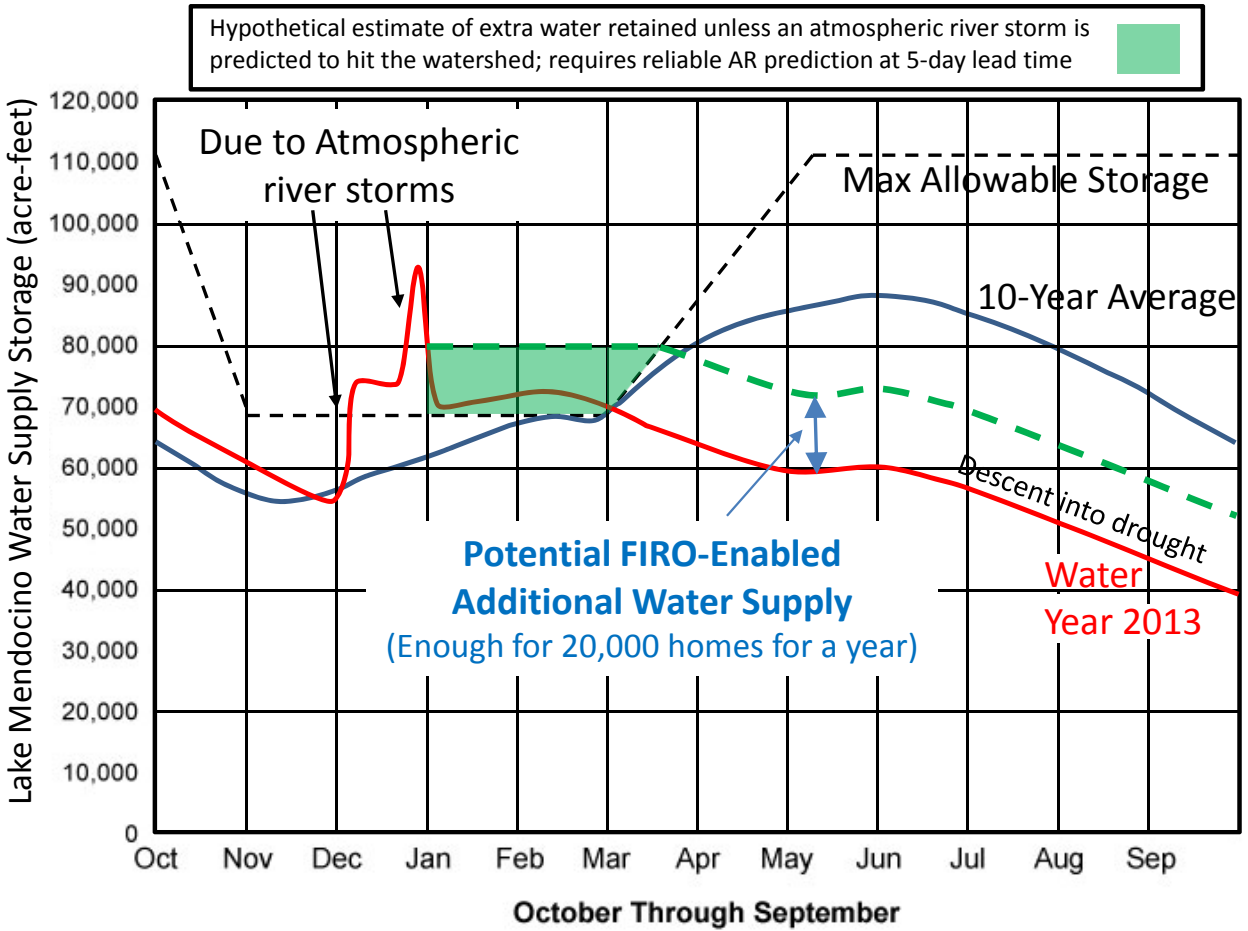

Atmospheric Water Vapor Content
1200 UTC 2 Dec 2012
Russian River basin
Atmospheric River
Latitude
Longitude
50
40
30
20
-160
-150
-140
-130
-120
Total Precipitable Water (mm)
60
50
40
30
20
10

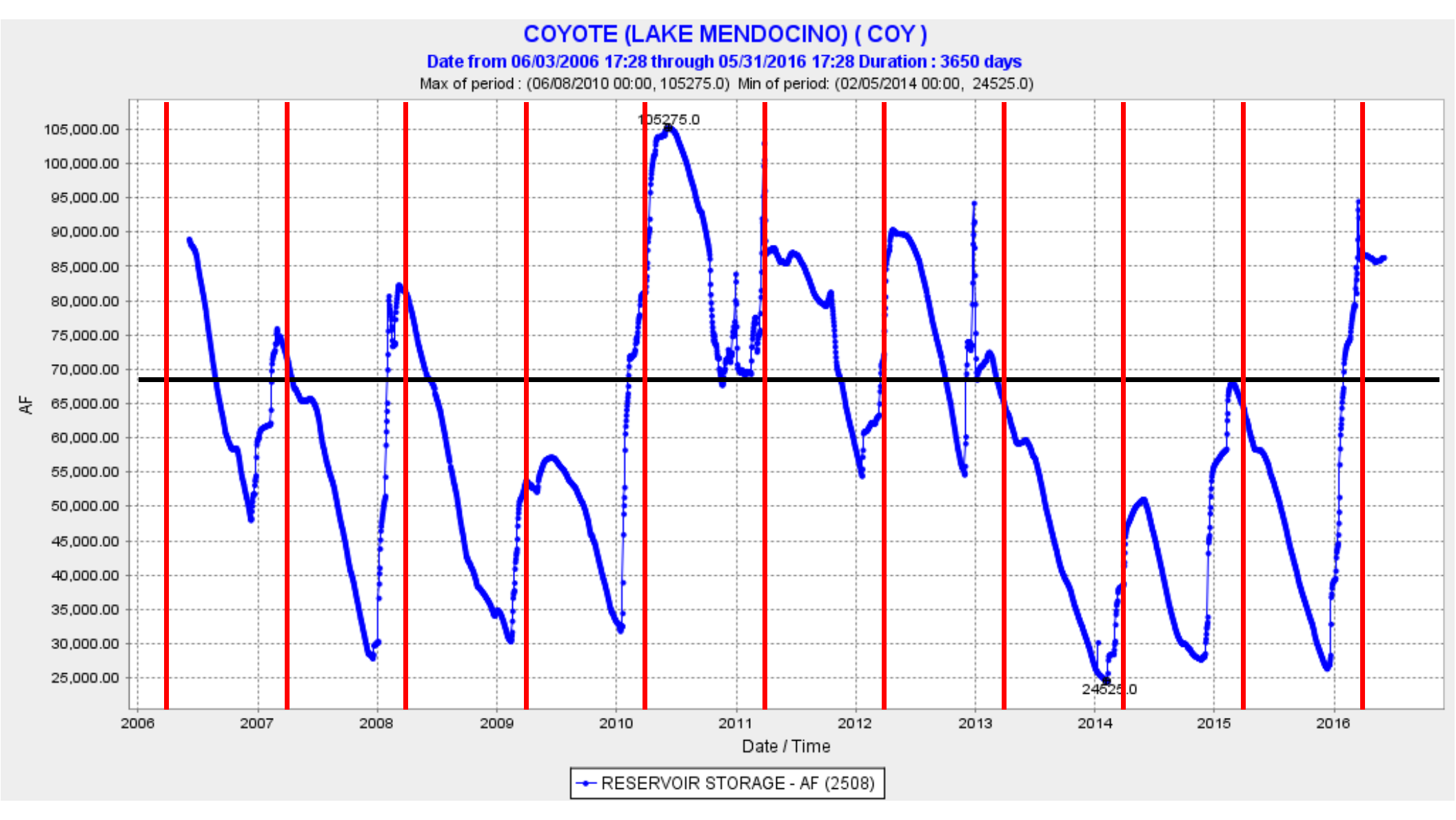
Atmospheric River Events 20 Nov-3 Dec 2012



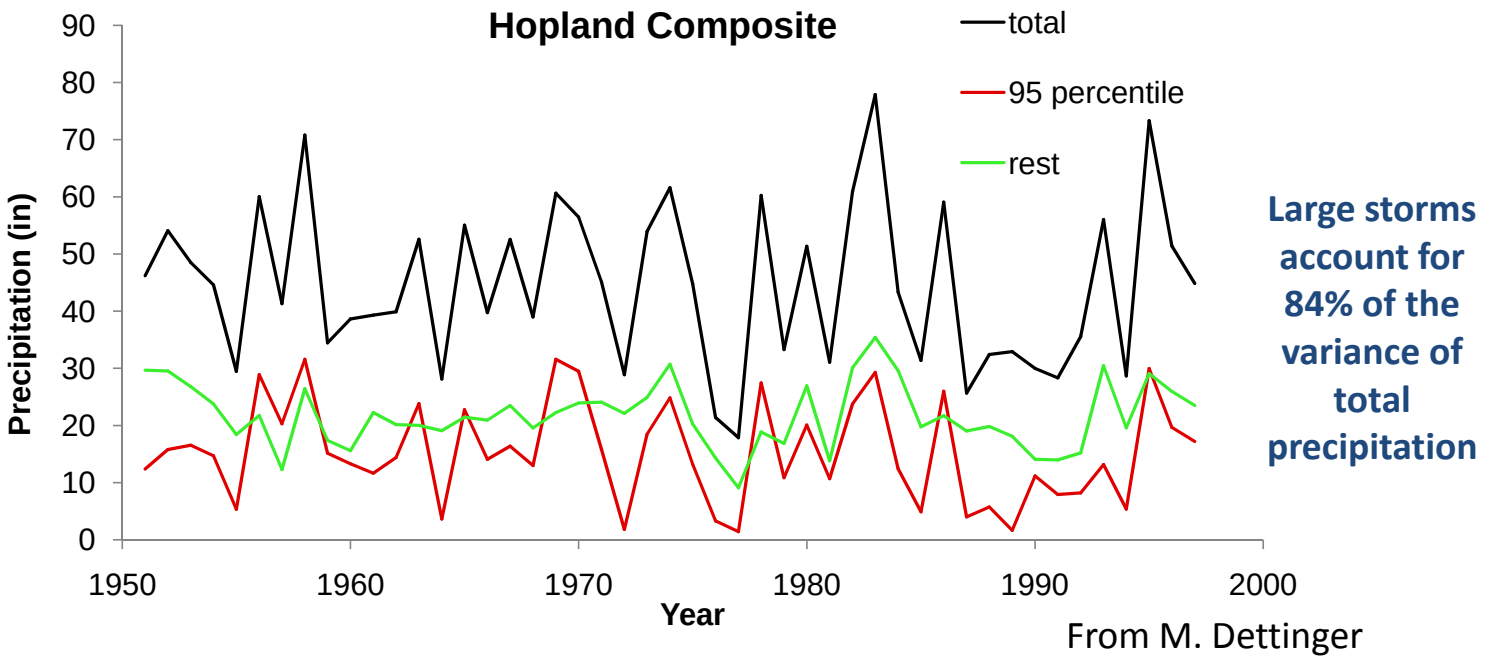
Animation courtesy of Don Murray (NOAA/ESRL/PSD)

Lake Mendocino Forecast-Informed Reservoir Operations Concept




COYOTE (LAKE MENDOCINO) (COY)
Date from 06/03/2006 17:28 through 05/31/2016 17:28 Duration : 3650 days
Max of period : (06/08/2010 00:00, 105275.0) Min of period: (02/05/2014 00:00, 24525.0)
105275.0
24525.0
105,000.00
100,000.00
95,000.00
90,000.00
85,000.00
80,000.00
75,000.00
70,000.00
65,000.00
60,000.00
55,000.00
50,000.00
45,000.00
40,000.00
35,000.00
30,000.00
25,000.00
AF
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Date / Time
RESERVOIR STORAGE - AF (2508)

Atmospheric Rivers Drive Droughts & Floods



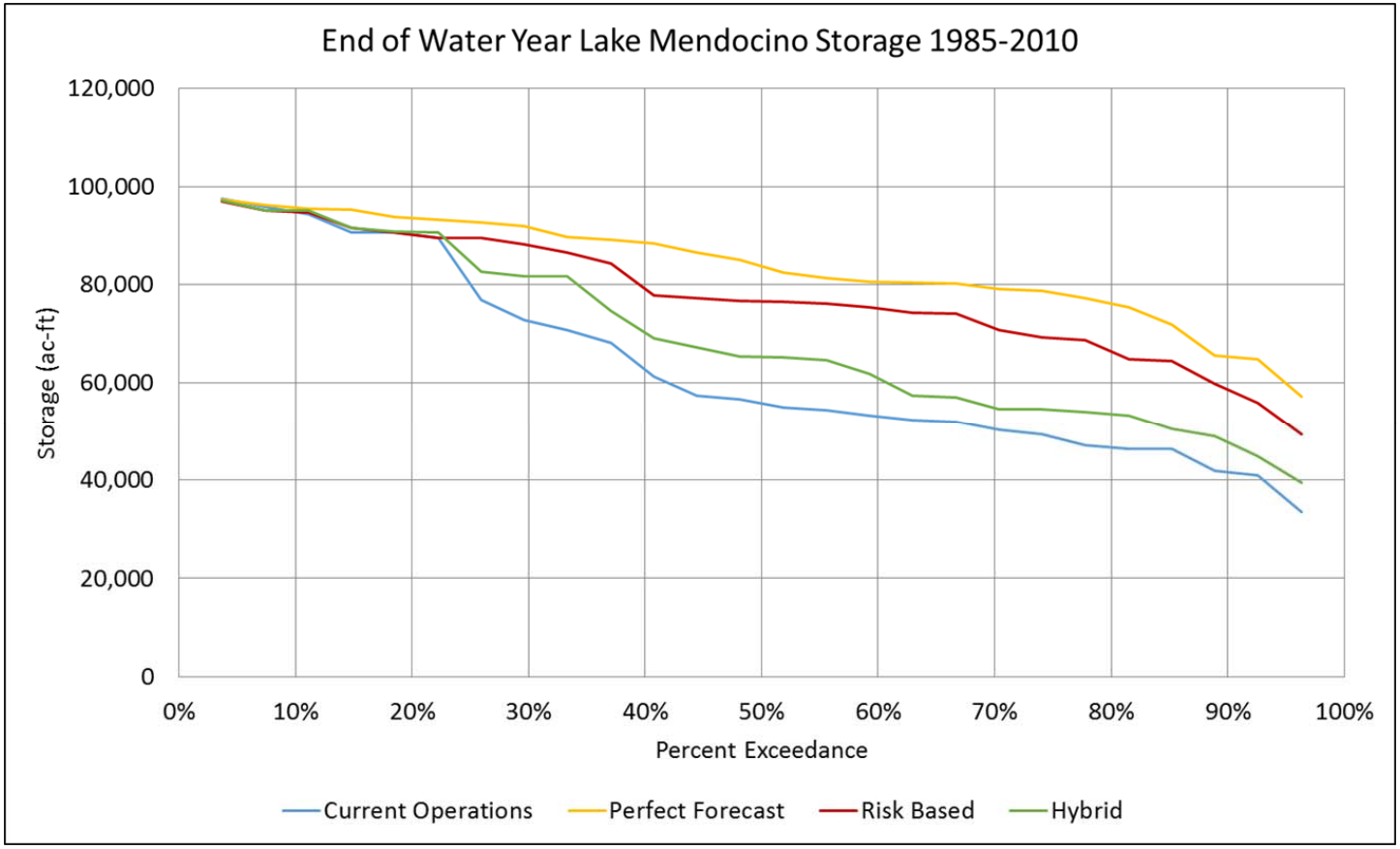
Large storms account for 84% of the variance of total precipitation

From M. Dettinger

Early Outputs from Lake Mendocino FIRO

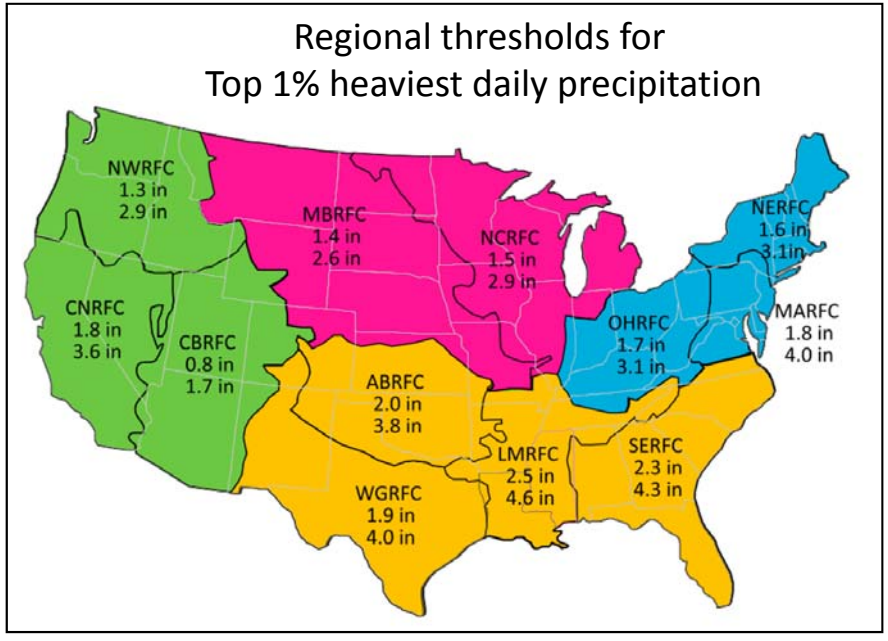
FIRO Potentially Improves Water Storage

Preliminary Modeling Results



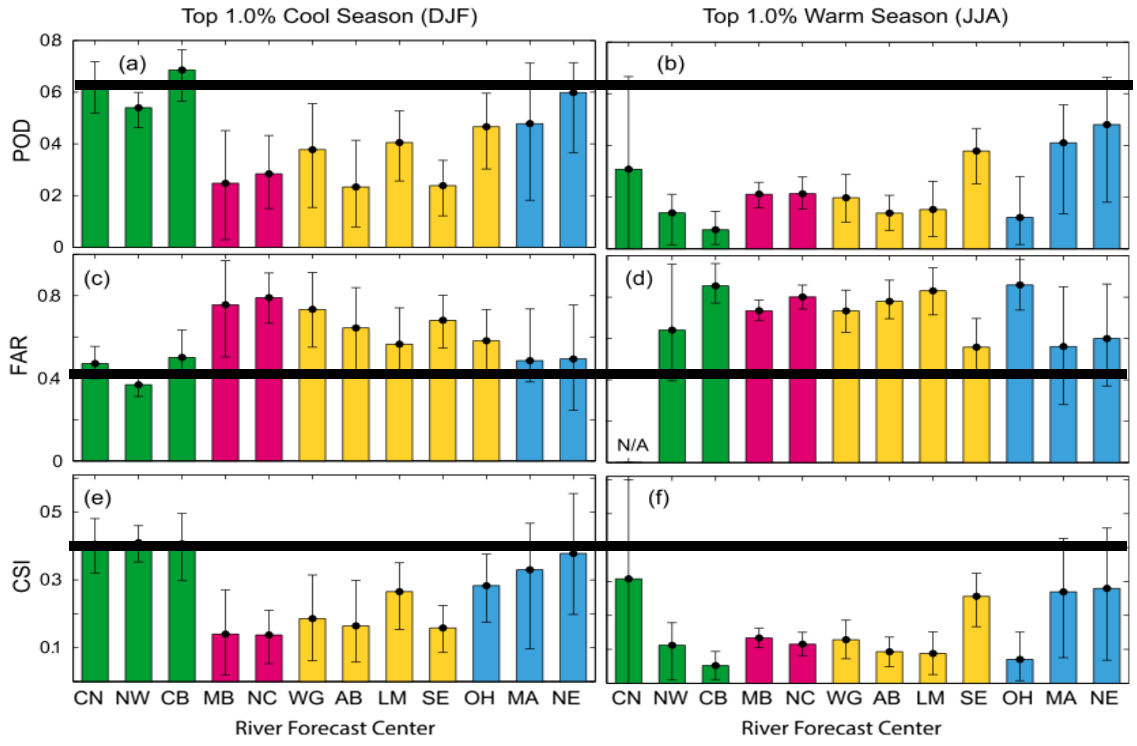
Extreme quantitative precipitation forecast performance at the Weather Prediction Center from 2001 to 2011

Sukovich, E. M., F. M. Ralph, F. E. Barthold, D. W. Reynolds and D. R. Novak *Wea. Forecast.* (2014)



Used 32 km gridded QPE from NCEP/WPC from 2001-2011
>12,000,000 wet days

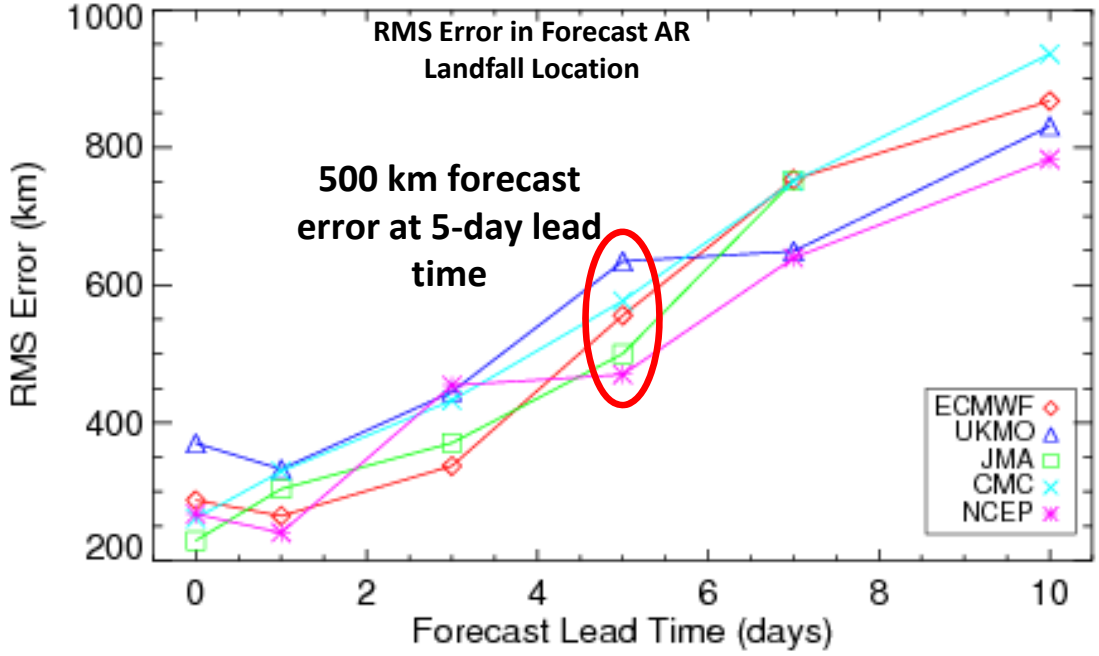
Slide courtesy of F.M. Ralph, Scripps/CW3E



Used 32 km gridded QPE and QPF from NCEP/WPC from 2007-2011. For 1-day lead time. Note QPF for Western RFC's and New England are best.

A Key Forecasting Challenge

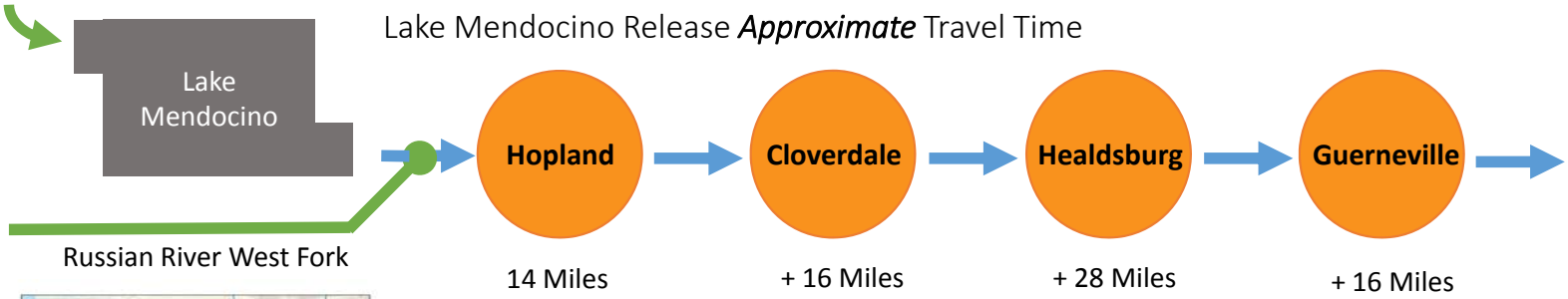
Forecasting AR landfall includes position errors larger than watersheds



Wick et al. 2013

How much forecast lead time is required to enable FIRO on Lake Mendocino?

10,000 AF could be released at 2500 cfs, which would take **2 days**



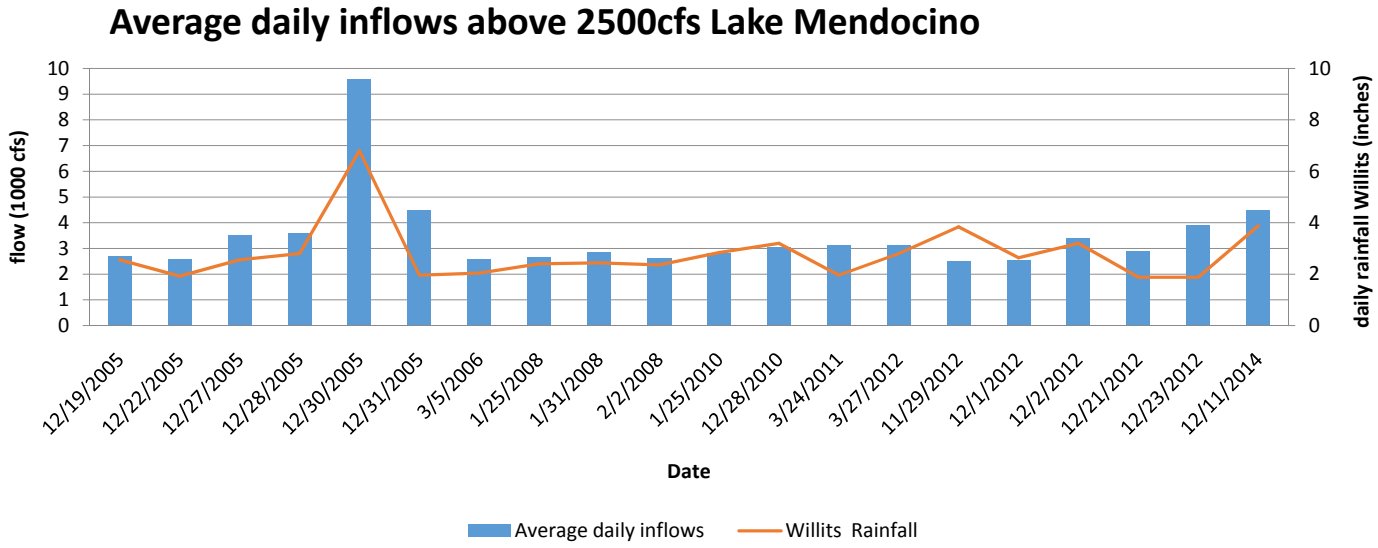
Total travel time ranges from 26hrs to 85hrs depending on flow rate (74miles traveled)*

Bottom Line: It takes 2 days to release 10,000 AF at 2500 cfs, plus 1.1 to 3.5 days for water released from Lake Mendocino to get past vulnerable communities downstream. In situations this would be needed, travel times will be on the short end of range.

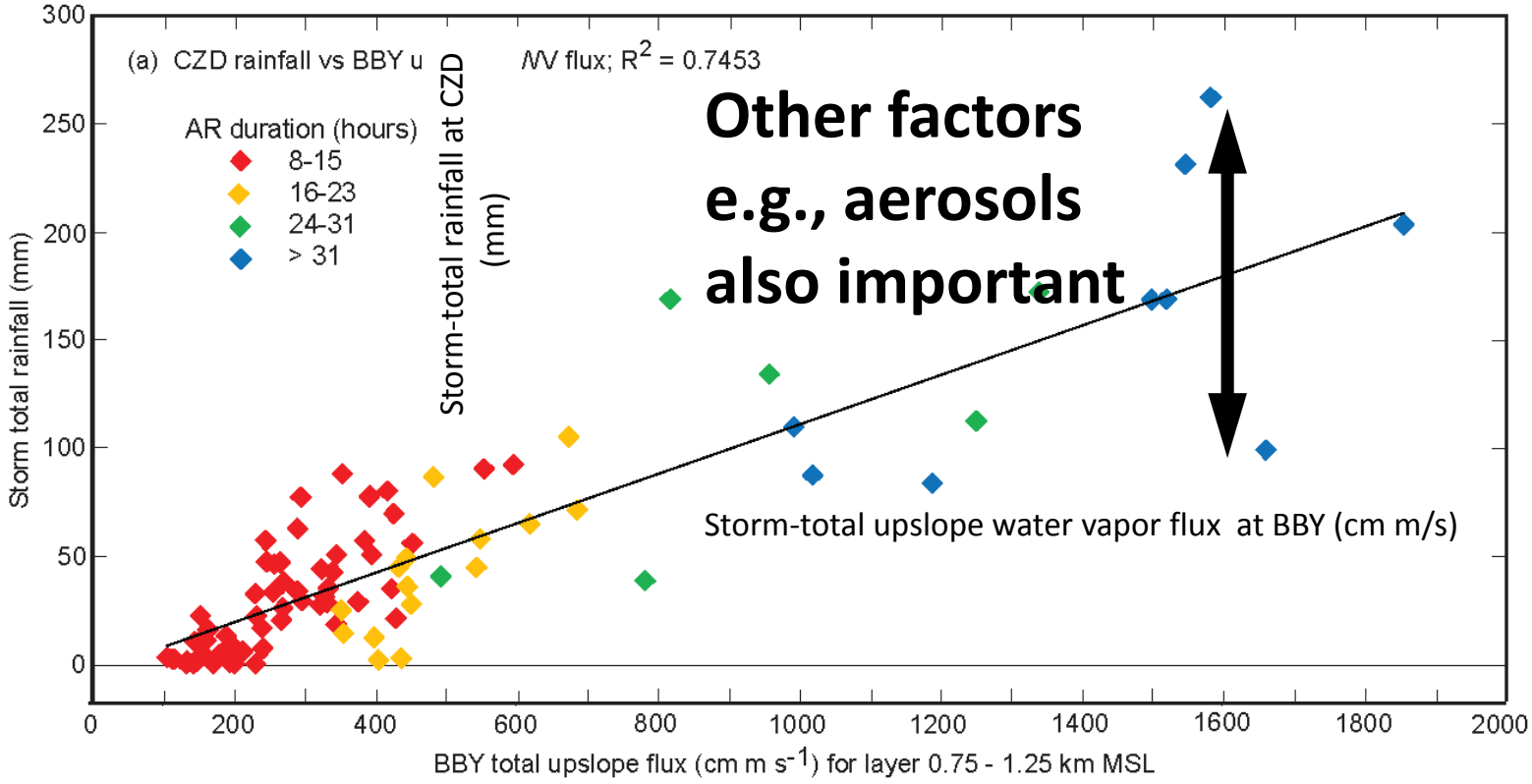
- This sets a forecast lead time requirement of <u>3-5 days</u> to predict landfalling atmospheric rivers.

*Uses information from Coyote Valley Dam and Lake Mendocino Water Control Manual (1986)

High Flows into Lake Mendocino and Willits daily rainfall – Requires 2” or more in 24hrs



CW3E



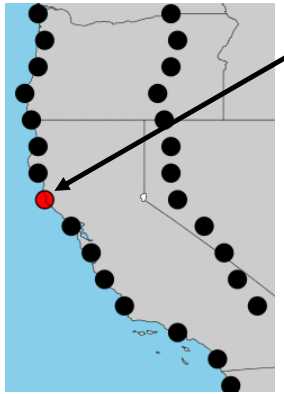
The greater the precipitation

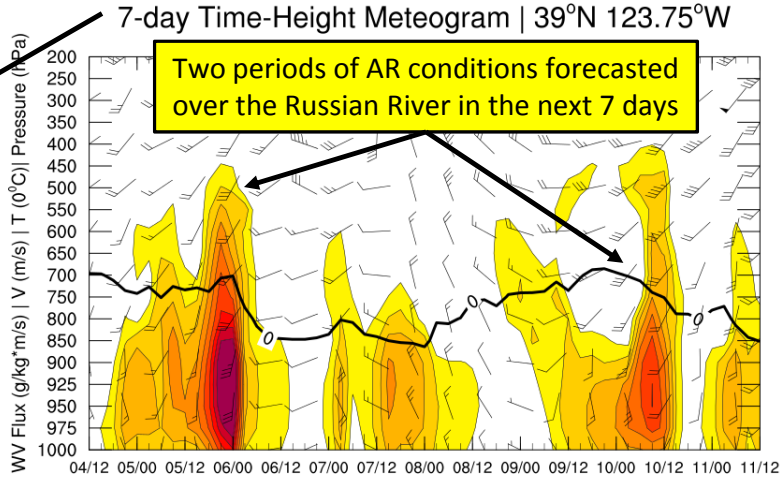
The greater the AR strength and duration

From Ralph et al. 2013, *J. Hydrometeorology*

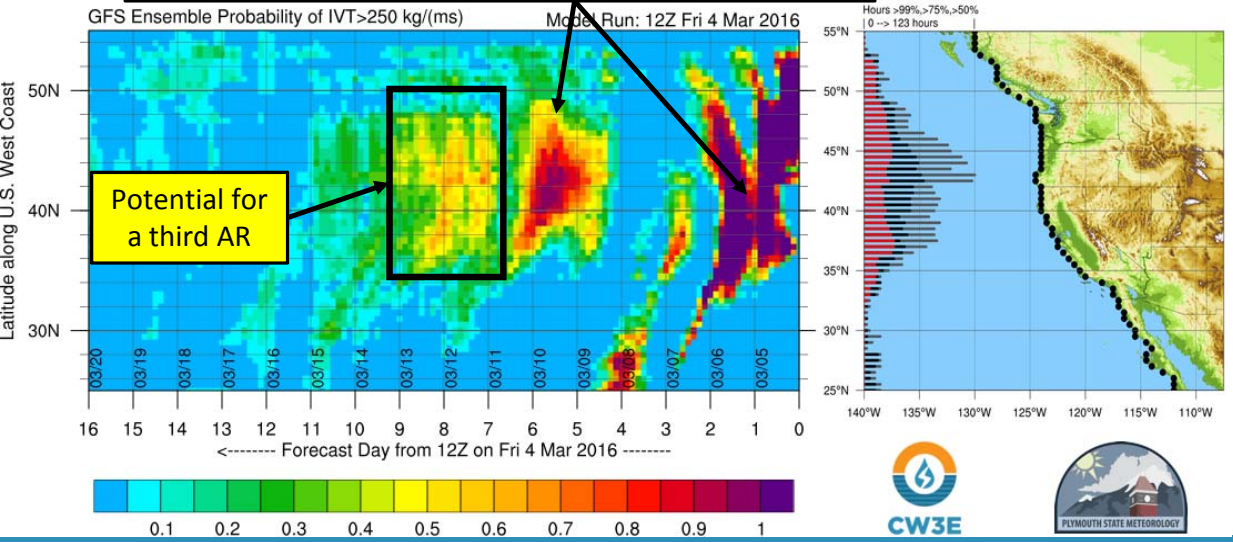
AR Forecast Tools

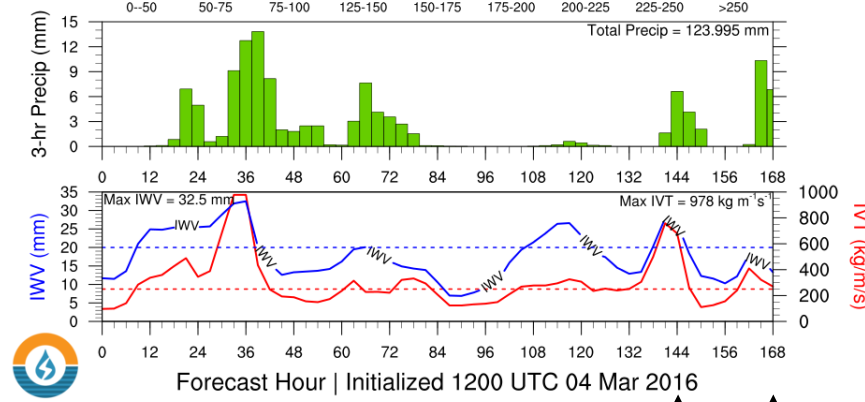
- Two ARs forecasted over the Russian River using the AR Landfall Tool and 7-day Meteograms
- Strong AR forecasted with high confidence at 6-7 day lead time
- AR Landfall tool shows potential for an AR at 7-9 day lead time
- Timing of landfall conditions based on AROs was within 6 hours of forecasted time for all three events





GFS Ensemble showed high confidence of two periods of AR conditions over the Russian River in the next 7 days





CW3E UCSD Scripps CW3E; Contact B.Kawzenuk/M. Ralph

6-7 day lead time

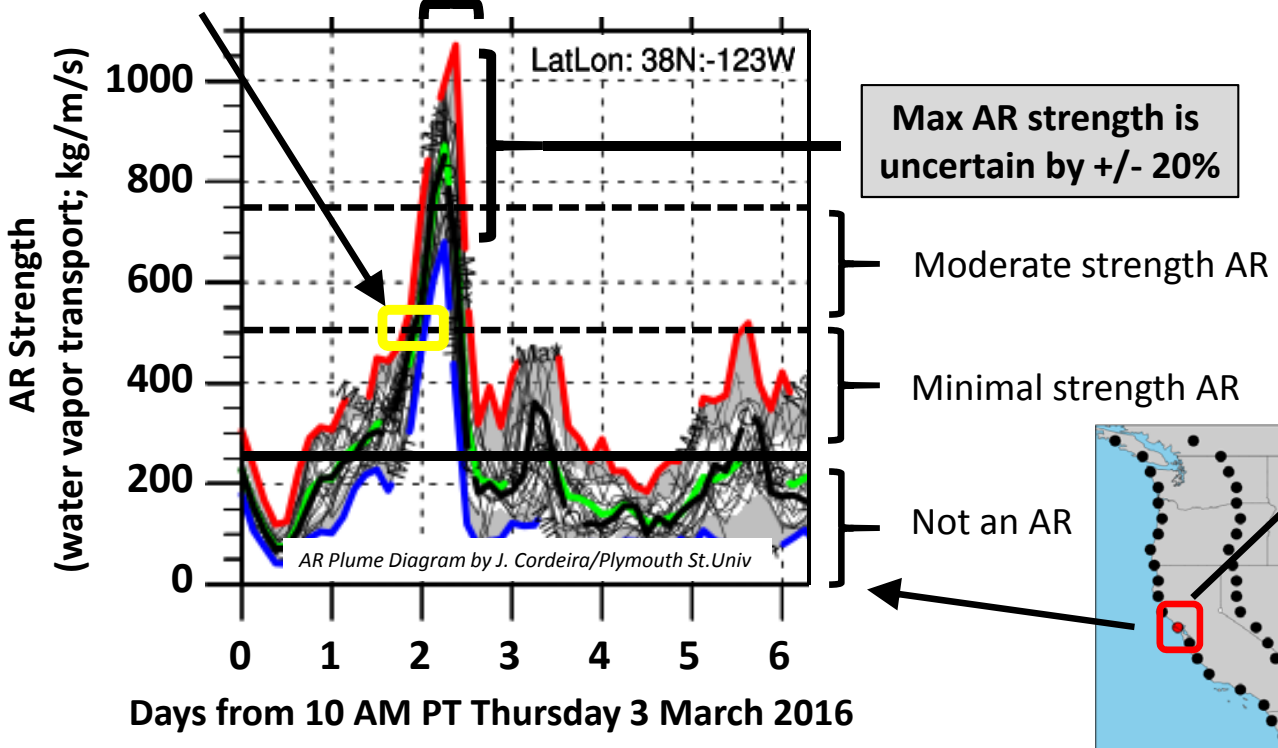
AR Landfall Tool is a joint effort of J. Cordeira (Plymouth State University), F.M. Ralph (CW3E/Scripps)

AR summary for Pt Reyes, CA area, including Russian River

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Onset of moderate-strength AR conditions Saturday morning

Normal-duration AR landfall (12-24 hours)

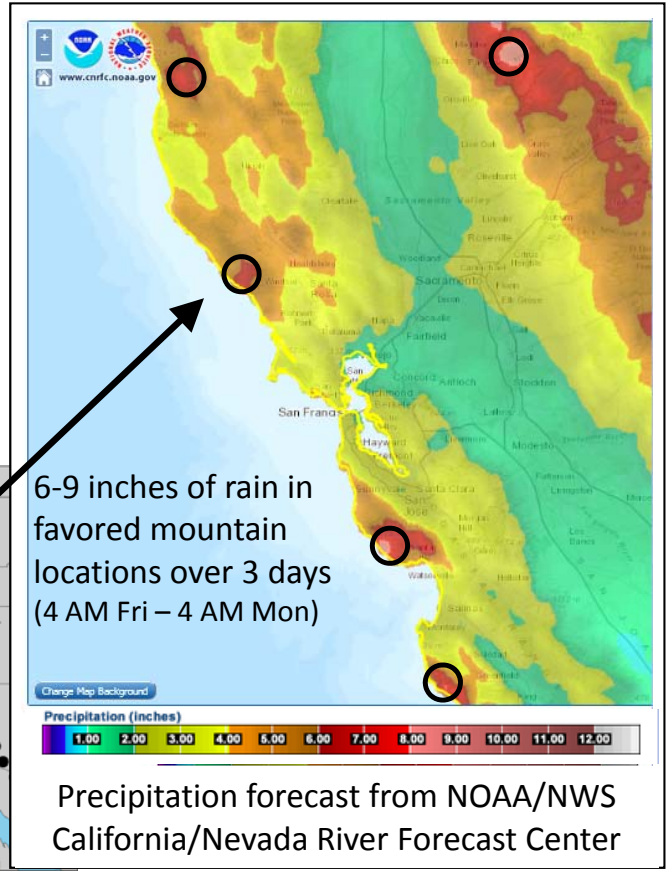


Max AR strength is uncertain by +/- 20%

Moderate strength AR

Minimal strength AR

Not an AR



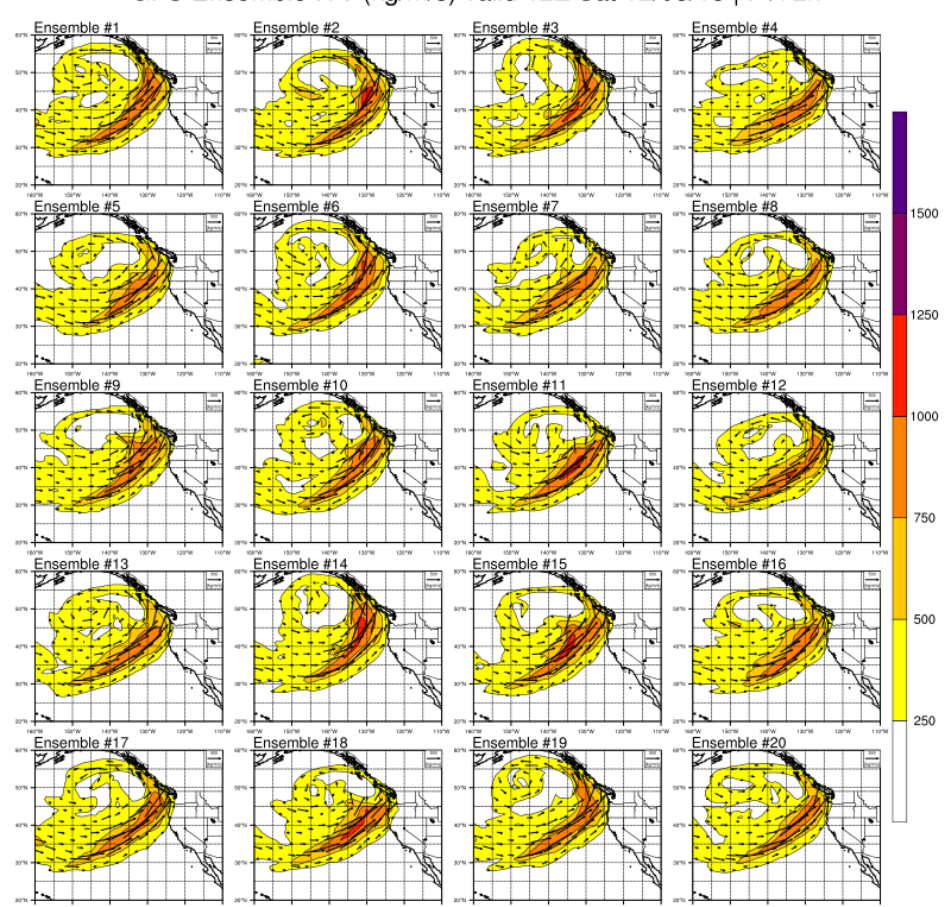
6-9 inches of rain in favored mountain locations over 3 days (4 AM Fri – 4 AM Mon)

Precipitation forecast from NOAA/NWS California/Nevada River Forecast Center

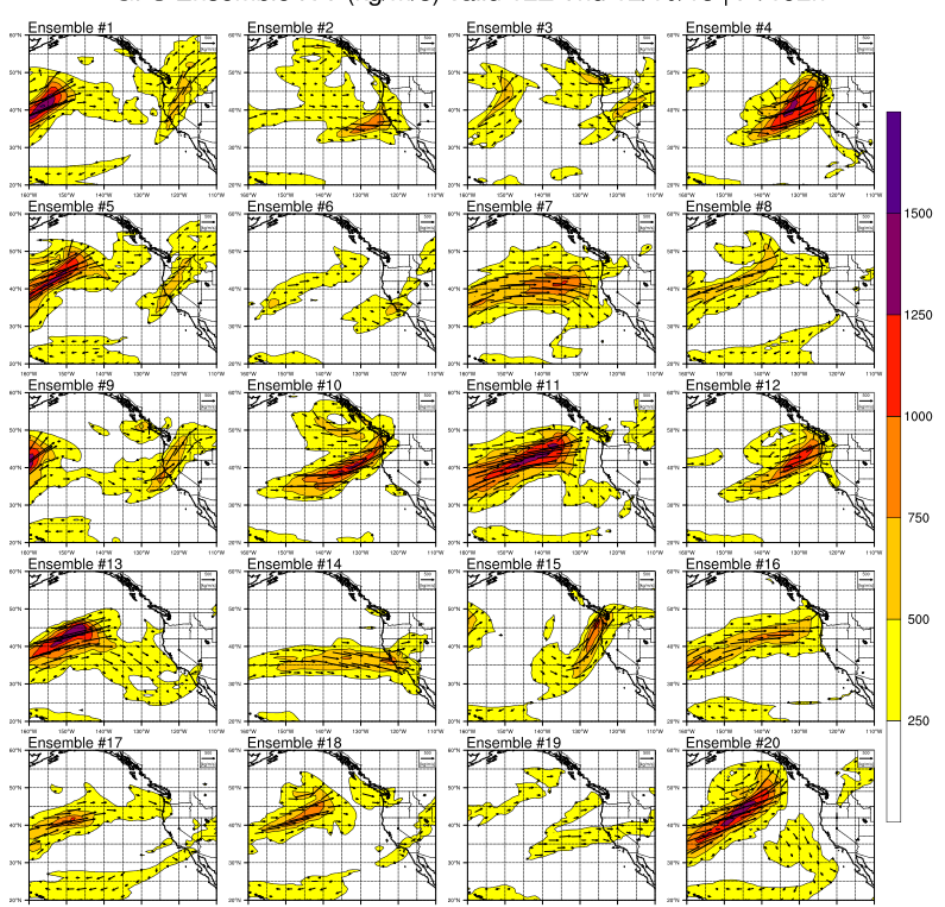
Summary by F.M. Ralph 8 AM PT Fri 4 March 2016

“Ensemble” prediction of ARs

3-days lead time

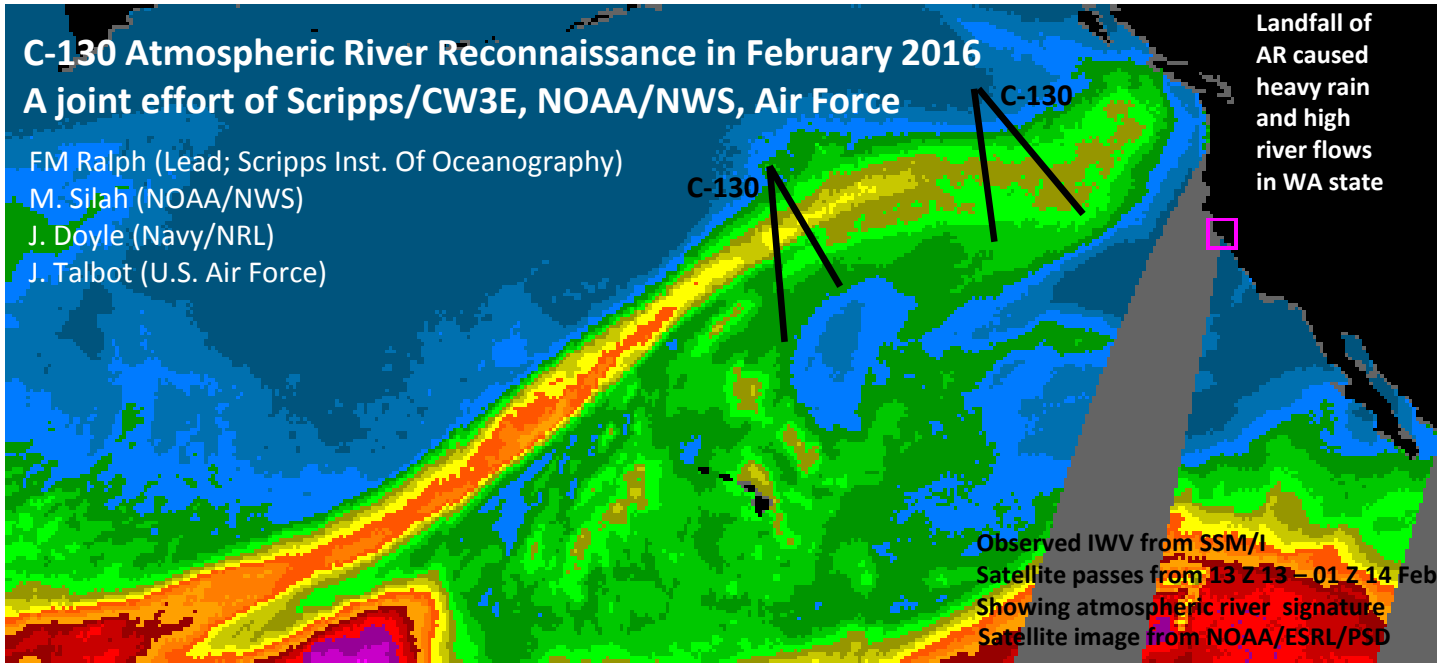


8-days lead time

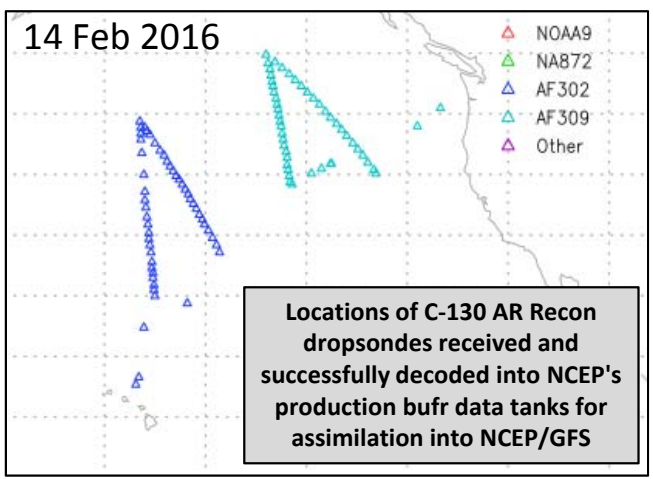


C-130 Atmospheric River Reconnaissance in February 2016
A joint effort of Scripps/CW3E, NOAA/NWS, Air Force

FM Ralph (Lead; Scripps Inst. Of Oceanography)
M. Silah (NOAA/NWS)
J. Doyle (Navy/NRL)
J. Talbot (U.S. Air Force)



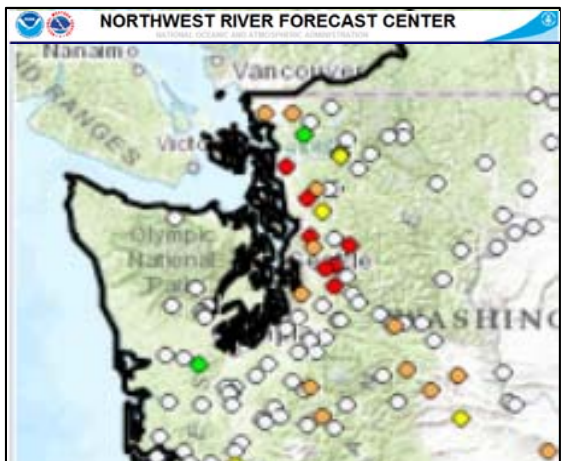
1st C-130 AR Recon Mission
13-14 Feb 2016
Dropsondes released for the 0000 UTC 14 Feb 2016 GFS data assimilation window



Locations of C-130 AR Recon dropsondes received and successfully decoded into NCEP's production bufr data tanks for assimilation into NCEP/GFS

Air Force C-130 Aircraft – Weather Recon' Squadron

Center for Western Weather and Water Extremes



NWRFC flood forecast map as of 1500 UTC 15 Feb showing several rivers predicted to reach flood stage on 15-16 Feb (red dots)

Summary

- Water management operations must respond to highly variable weather conditions – particularly Atmospheric Rivers
- FIRO shows promise for improved reservoir water supply & in-stream flows
- Must ensure that flood protection won't be compromised
- Build resiliency & defer/avoid expensive capital projects
- Demonstration project employs technical/scientific innovation utilizing a collaborative multi-agency partnership
- Implementation will be incremental (FIRO version 1, version 2, etc.)

- Major next steps:
  - complete "preliminary viability assessment"
  - Complete "full viability assessment"

Lake Mendocino FIRO summary information is available at

CW3E.UCSD.EDU


Thank
you!