Seasonal hydrologic prediction + HEPEX + GHP =
a proposed high-impact cross-cutting project

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GEWEX GHP Panel Meeting
December 11, Cal Tech, Pasadena, CA

Outline

- HEPEX Background
- The Value of Seasonal Hydrologic Prediction
  - An example from practice
- Hydrologic Prediction Science & Research
- A HEPEX-GHP Intercomparison Experiment?

HEPEX Overview

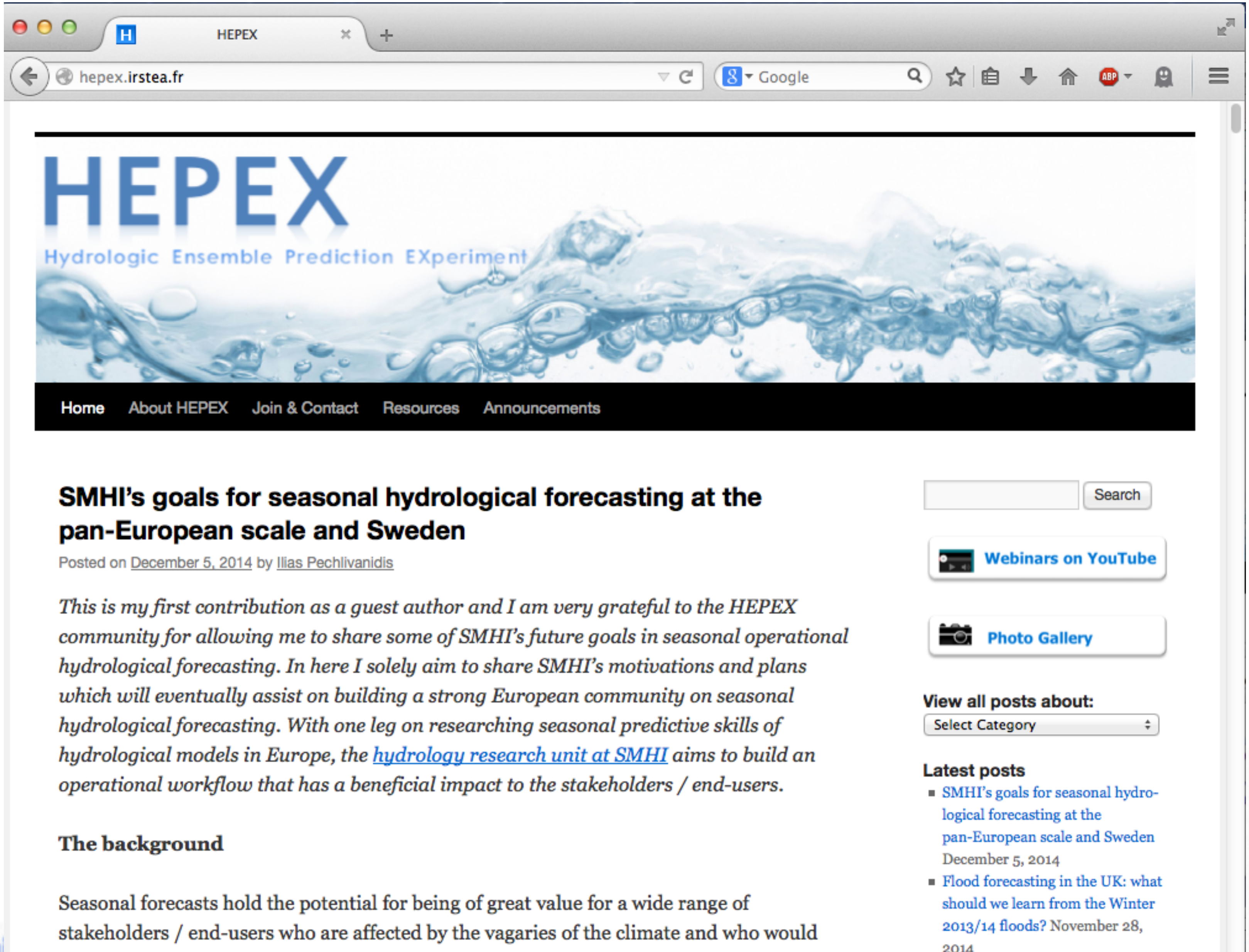
HEPEX mission:

To demonstrate the added value of hydrological ensemble predictions (HEPS) for emergency management and water resources sectors to make decisions benefitting the economy, public health and safety.

Key questions of HEPEX:

- What adaptations are required for meteorological ensemble systems to be coupled with hydrological ensemble systems?
- How should the existing hydrological ensemble prediction systems evolve to account for all sources of uncertainty within a forecast?
- What is the best way for the user community to take advantage of ensemble forecasts and to make better decisions based on them?

HEPEX is now best known via an active website


HEPEX

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HEPEX

Hydrologic Ensemble Prediction EXperiment

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SMHI's goals for seasonal hydrological forecasting at the pan-European scale and Sweden

Posted on December 5, 2014 by Ilias Pechlivanidis

This is my first contribution as a guest author and I am very grateful to the HEPEX community for allowing me to share some of SMHI's future goals in seasonal operational hydrological forecasting. In here I solely aim to share SMHI's motivations and plans which will eventually assist on building a strong European community on seasonal hydrological forecasting. With one leg on researching seasonal predictive skills of hydrological models in Europe, the hydrology research unit at SMHI aims to build an operational workflow that has a beneficial impact to the stakeholders / end-users.

The background

Seasonal forecasts hold the potential for being of great value for a wide range of stakeholders / end-users who are affected by the vagaries of the climate and who would

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- SMHI's goals for seasonal hydrological forecasting at the pan-European scale and Sweden December 5, 2014
- Flood forecasting in the UK: what should we learn from the Winter 2013/14 floods? November 28, 2014

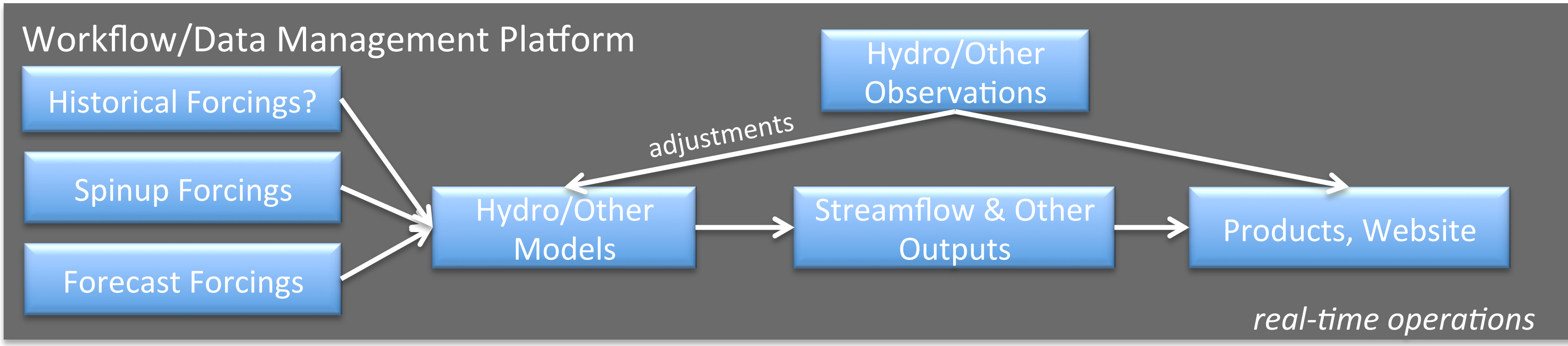
HEPEX Activities

- Community Meetings & Workshops
- Many smaller sessions: AGU, EGU, GEWEX, EMS, AMS, etc.
- Articles and Journal Special Issues
  - HESS: HEPEX Special Issue
  - EOS Article
  - BAMS Article
  - ASL Special Issues (2)
  - Hydrological Sciences
- Test-bed Projects (several)
- Experiments (several)
- Online Community
- Highlight Case Studies
- Webinars (regular)

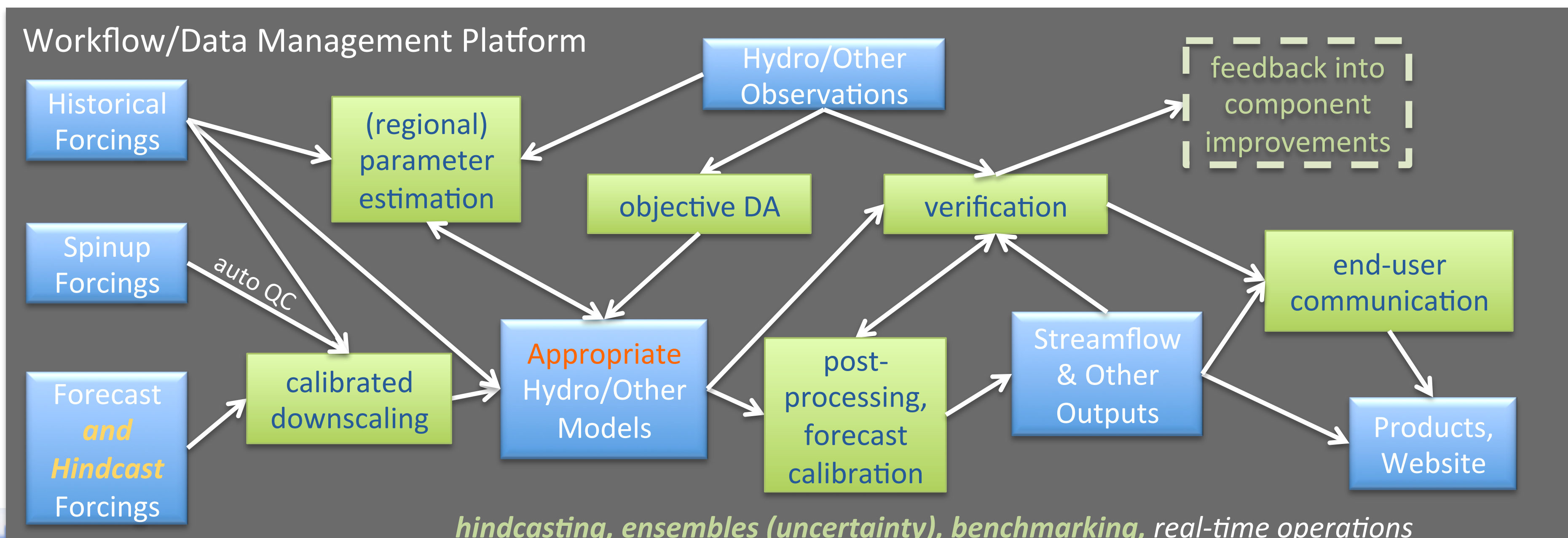
HEPEX
Hydrologic Ensemble Prediction EXperiment

HEPEX: Merging Science with Pragmatism

The Basics: Making a Prediction System Work → Models, Data, Systems



HEPEX: Making a Prediction System Work ***Well*** → Methods & Tradeoffs



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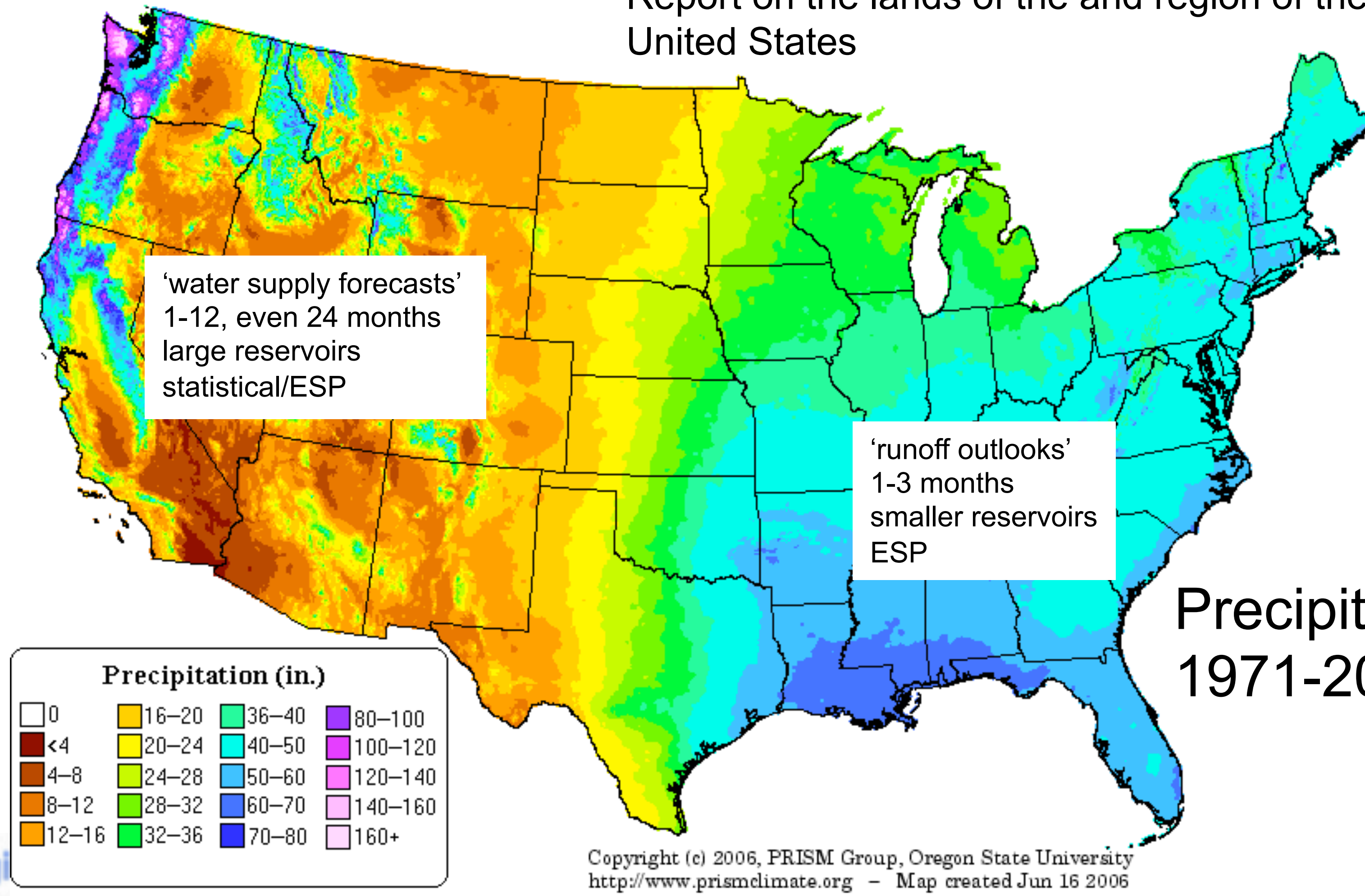
The Arid Lands

Many droughts will occur; many seasons in a long series will be fruitless; and it may be doubted whether, on the whole, agriculture will prove remunerative.

John Wesley Powell, 1879
Report on the lands of the arid region of the United States



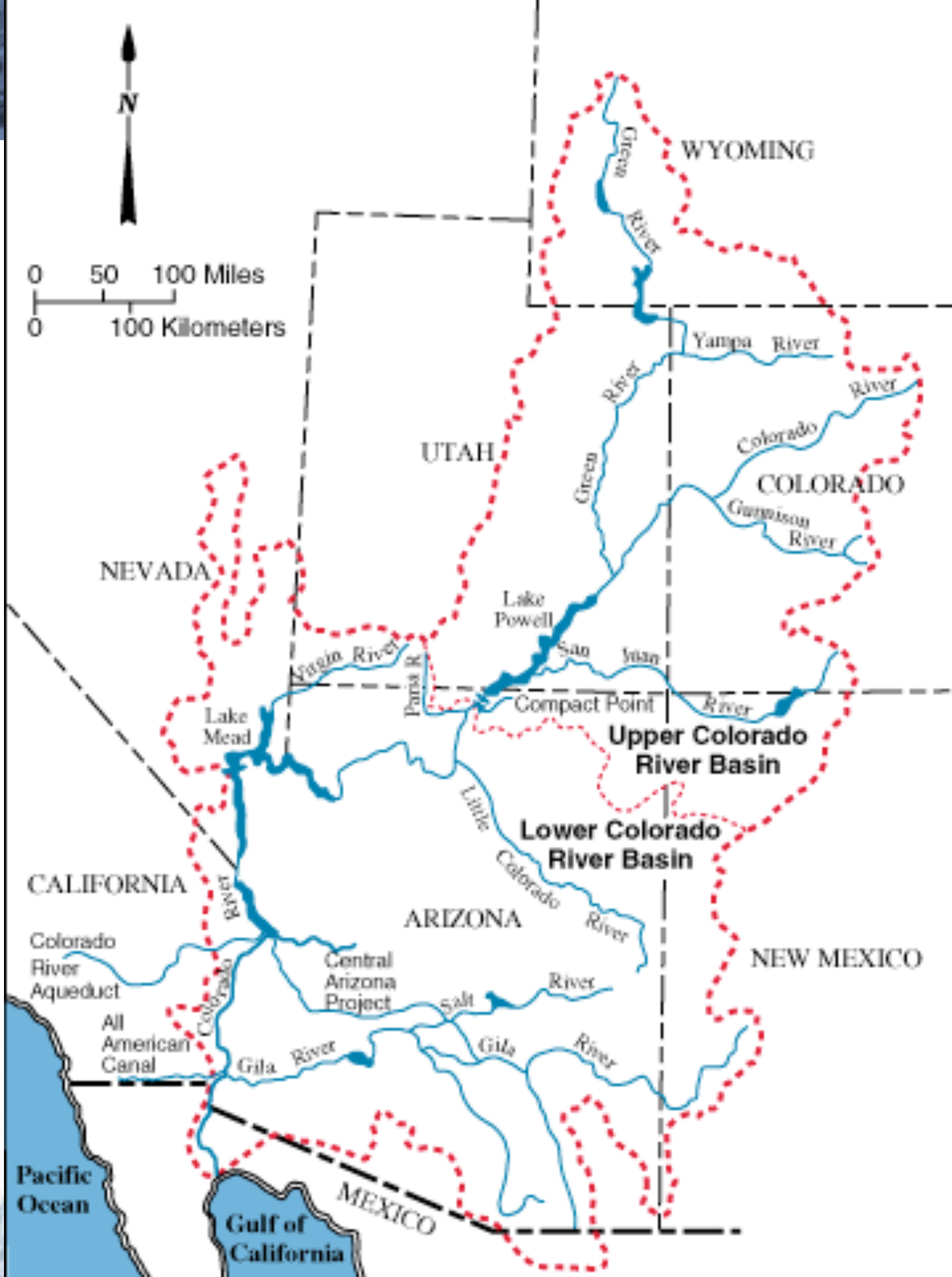
‘water supply forecasts’
1-12, even 24 months
large reservoirs
statistical/ESP

‘runoff outlooks’
1-3 months
smaller reservoirs
ESP

Precipitation, 1971-2000

Colorado River

- 25 million people in 7 states rely on Colorado River water
- 3.5 million acres of irrigation
- 85% of runoff comes from above 9000 feet
- Mean annual discharge is … (?)
- Storage capacity is about 60 MAF (4-5 times mean annual flow)



Management using Seasonal Flow Forecasts

Upper Colorado Reservoir Management

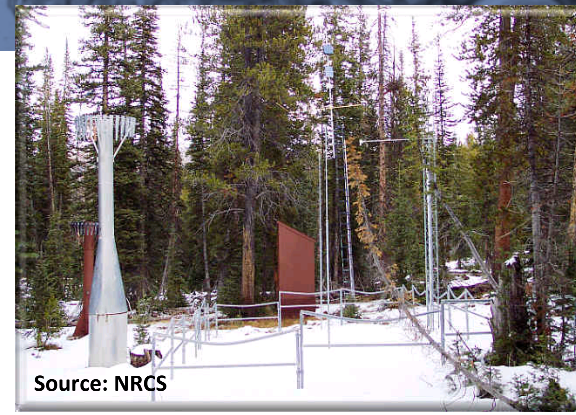
Water transfer decision from upper to lower basin states depends on forecast

Lake Powell		
Elevation (feet)	Opertaions According to Interim Guidelines	Live Storage (MAF)
3,700	**Equalization Tier** Equalize, Avoid Spills or Release 8.23 MAF	24.3
3,636 - 3,666 (2008-2026)		15.5 - 19.3 (2008-2026)
	Upper Elevation Balancing Tier[1] Release 8.23 MAF; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 MAF	
3,635 1/1/10 Projection		*15.4 1/1/010Projection*
3,575		9.5
	Mid-Elevation Release Tier Release 7.48 MAF; if Lake Mead < 1,025 feet, Release 8.23 MAF;	
3,525		5.9
	Lower Elevation Balancing Tier Balance contents with a min/max release of 7.0 and 9.5 MAF	
3,490		4.0
3,370		0

Lake Mead		
Elevation (feet)	Opertaions According to Interim Guidelines	Live Storage (MAF)
1,220	**Flood Control, 70R or ICS Surplus**	25.9
1,200		22.9
	Domestic or ICS Surplus	
1,145		15.9
1,098 1/1/10 Projection	**Normal Operations or ICS Surplus**	*11.4 1/1/10 Projection*
1,075		9.4
1,050		
1,025		
1,000		
895		

Simple Statistical Forecasting

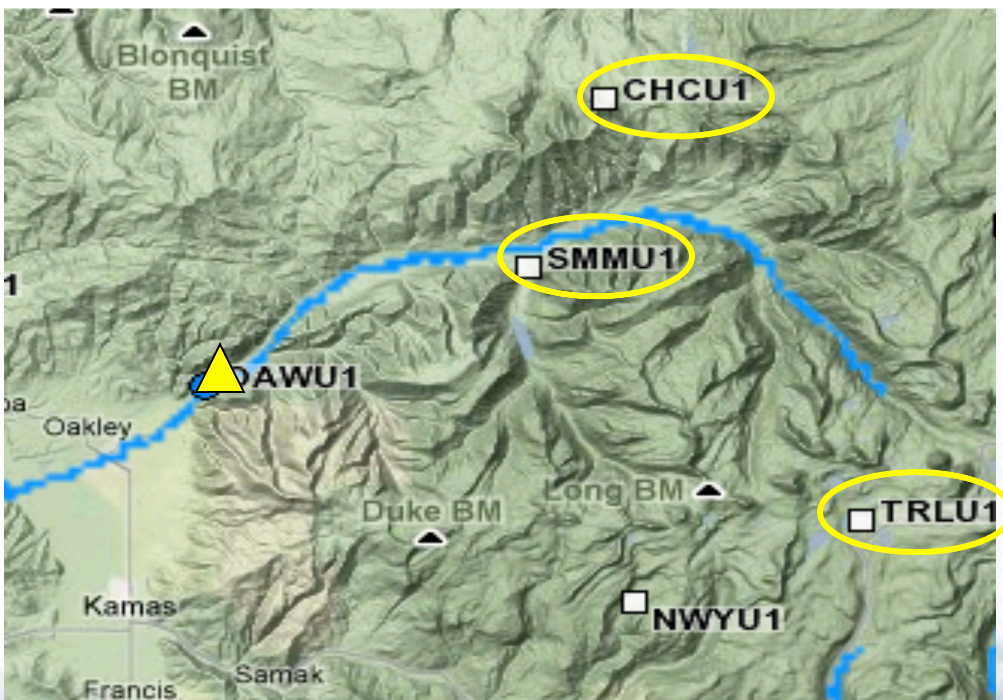
Trial Lake SNOTEL



Sample Equation for April 1 forecast of April-July Flow:

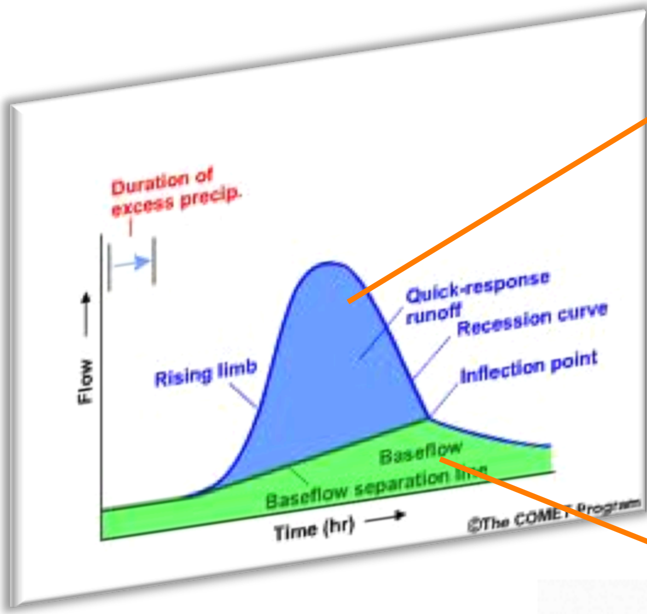
April-July volume Weber @ Oakley =

+ 3.50 * Apr 1st Smith & Morehouse (SMMU1) Snow Water Equivalent
+ 1.66 * Apr 1st Trial Lake (TRLU1) Snow Water Equivalent
+ 2.40 * Apr 1st Chalk Creek #1 (CHCU1) Snow Water Equivalent
- 28.27

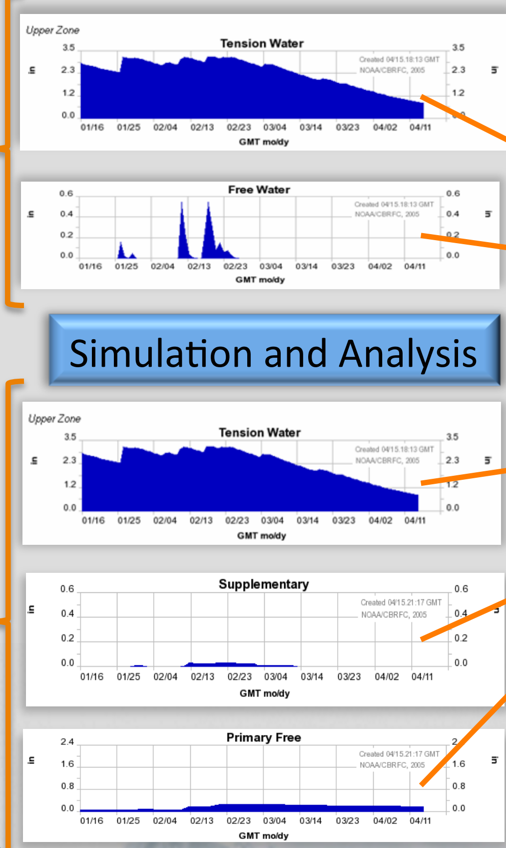


End-to-End Operational Forecast Process

Data Preparation | **Modeling** | Dissemination

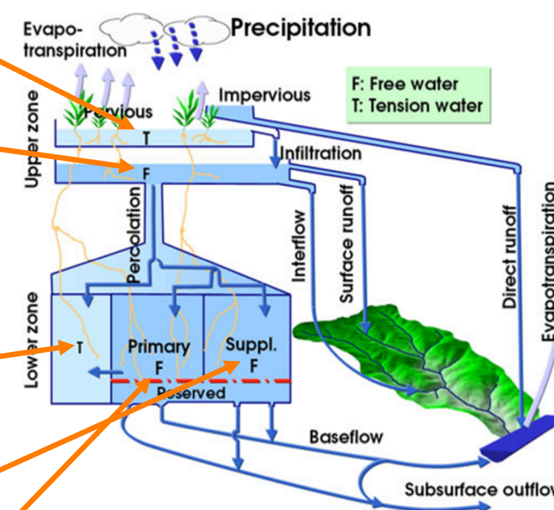


Observed Hydrology



Simulation and Analysis

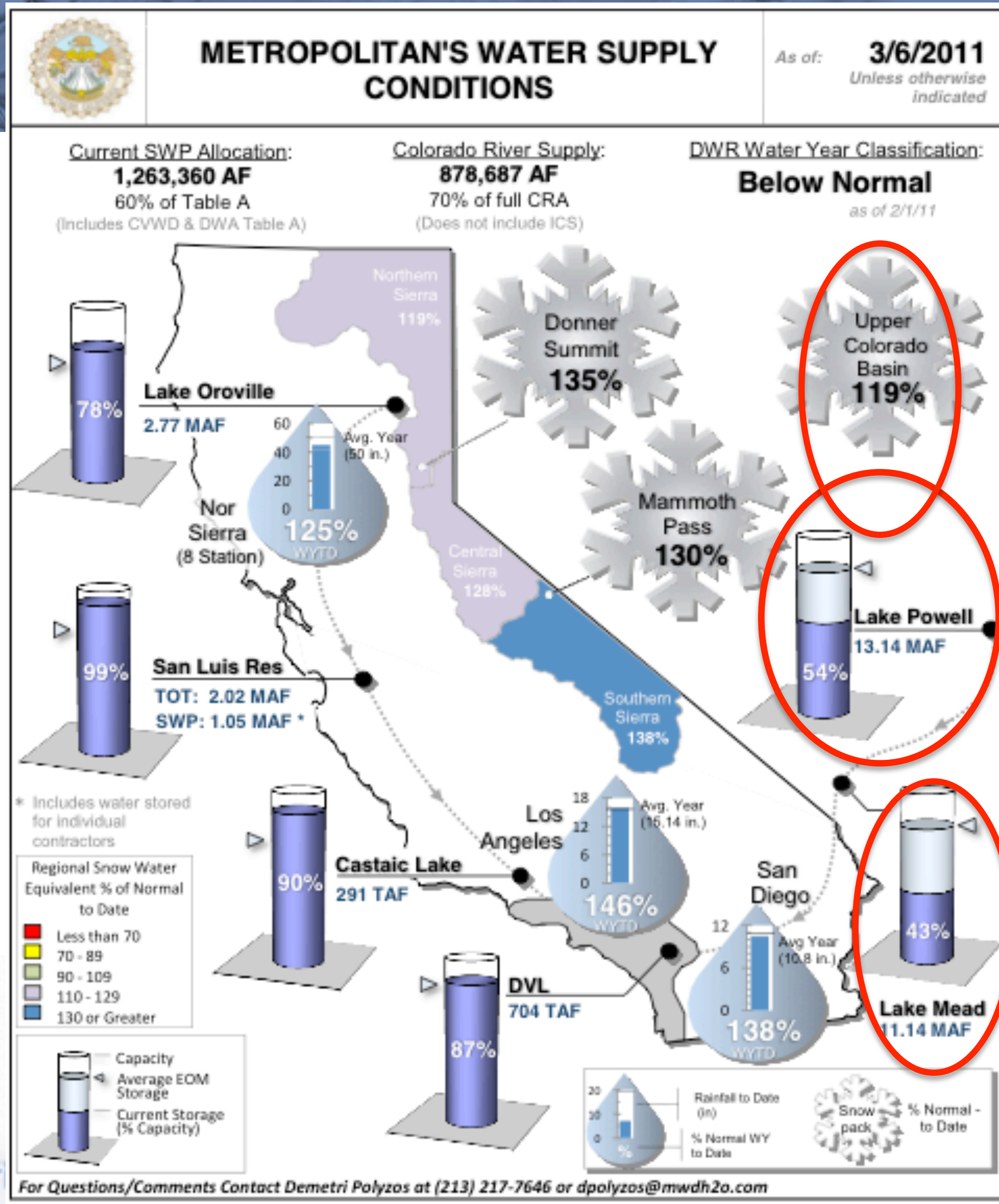
Temperature index model for simulating snowpack accumulation and melt ➔



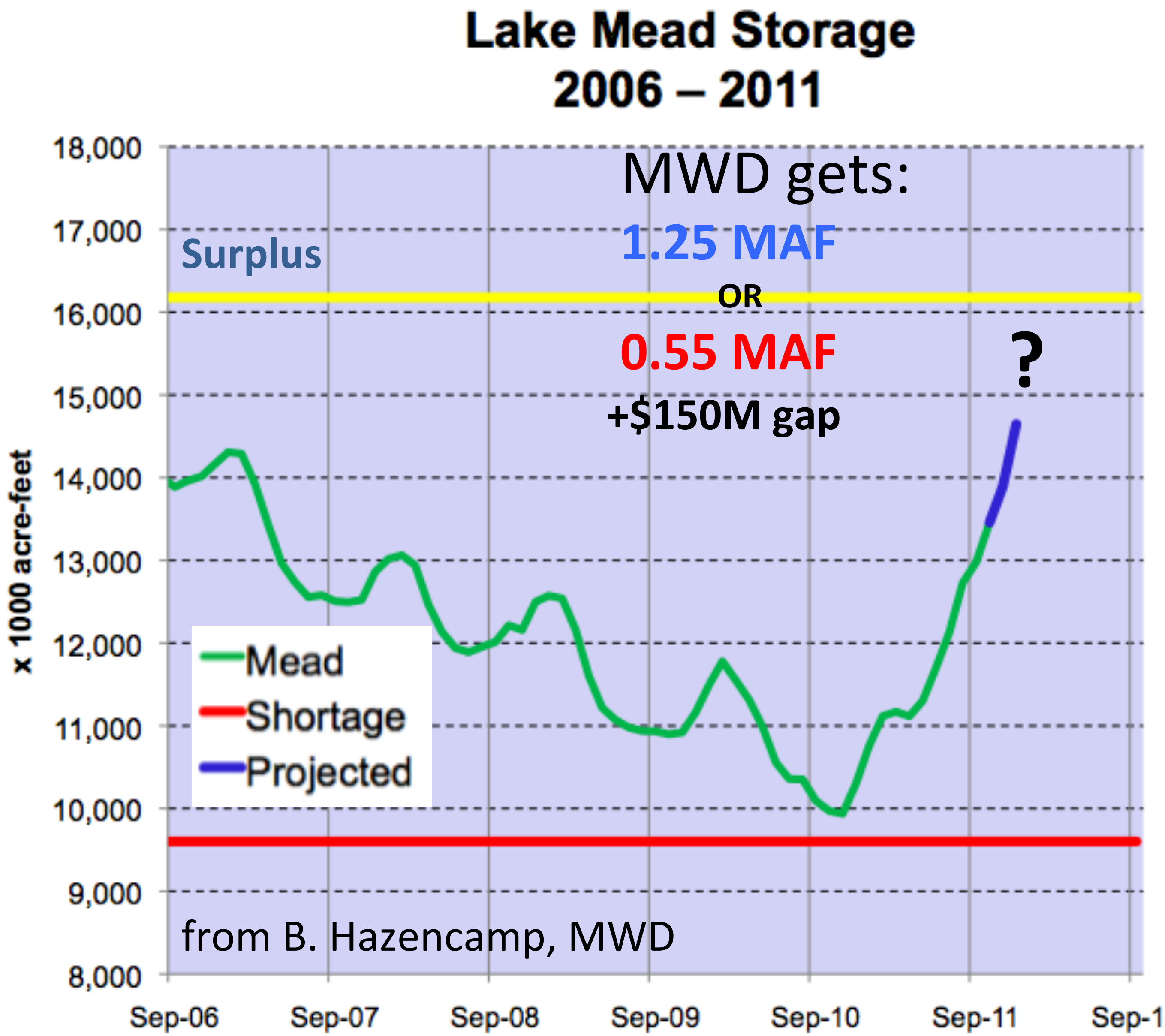
Sacramento Soil Moisture Accounting Model

Stakeholder Example

- Metropolitan Water District (California)
  - Supplies water to ~20m residents in southern California (including L.A.)
  - Issues weekly water supply conditions map (right) based on RFC, CA DWR, and NRCS forecasts and data



Seasonal streamflow prediction is critical



One example:
Met. Water Dist. of
S. California (MWD)

Value

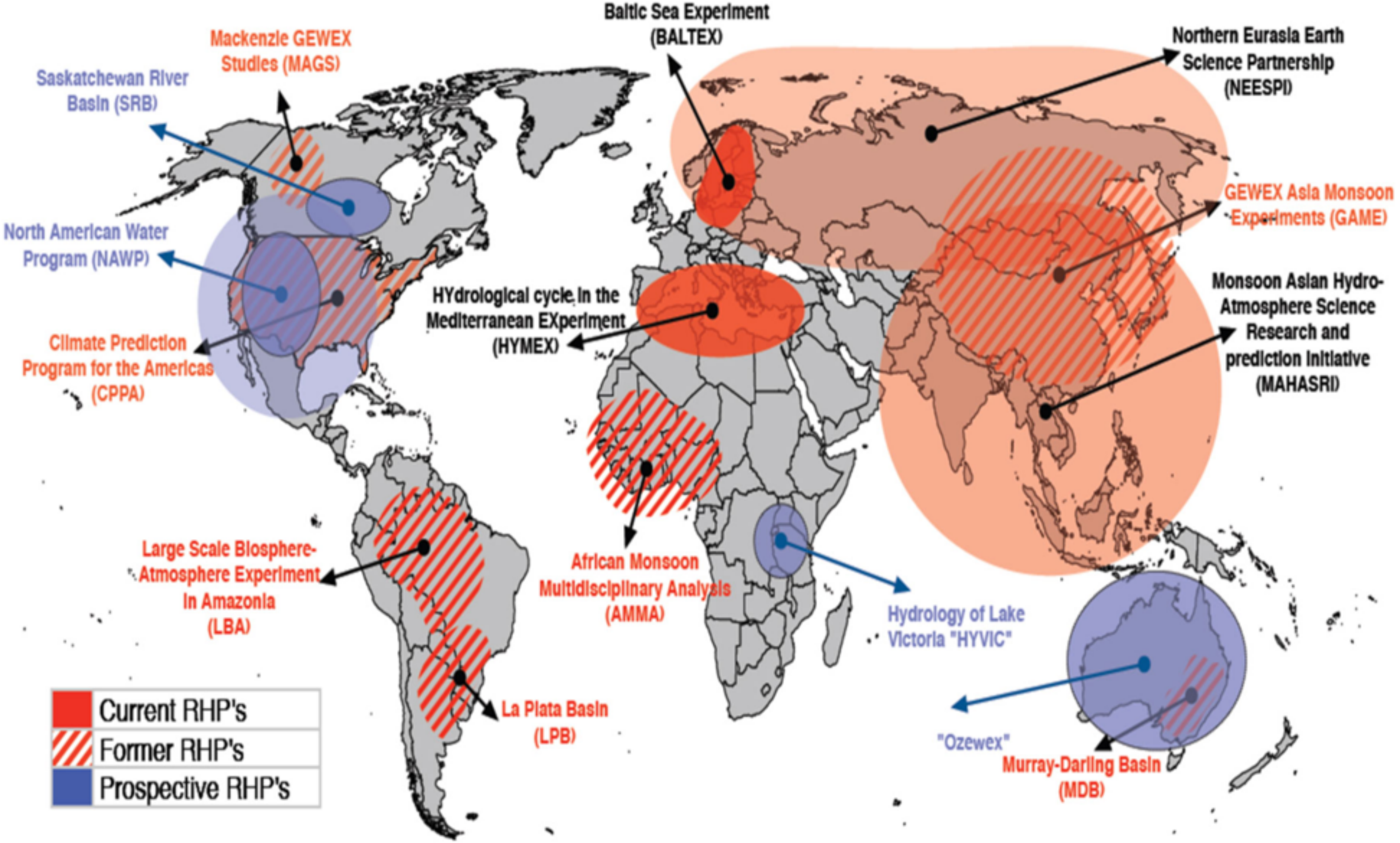
- Damage from 1/10 AZ storm: $11m[a]
- Damage from 6/10 UT flooding: $6.5m[a]
- Damage from 12/10 UT/NV storm: $11m[a]
- Damage from 09/13 Boulder flood: $1b[c]

- Colorado River average runoff: 12.4 MAF
- Replacement value at $330/AF -> $4b[b]
  - Indirect multiplier ~3? **$12b**

The economic value of water resources typically greater than flooding damages

- Sources:
- a: WFO, FEMA (via stormdata); b: MWD (via Hasencamp, private communication)
- c: Wikipedia

GEWEX REGIONAL HYDROCLIMATE PROJECTS



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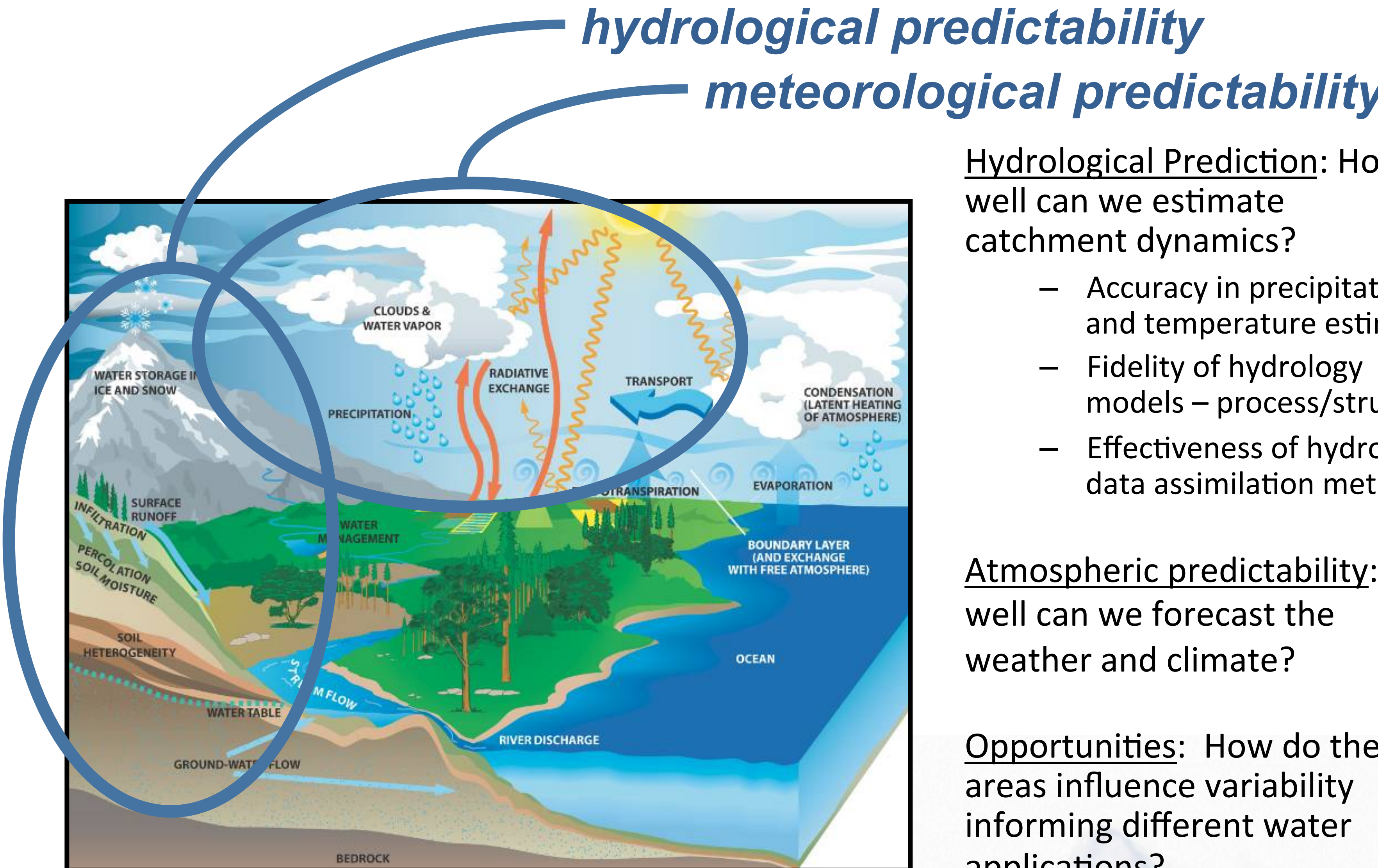
hydrologic prediction science questions



Water Cycle (from NASA)

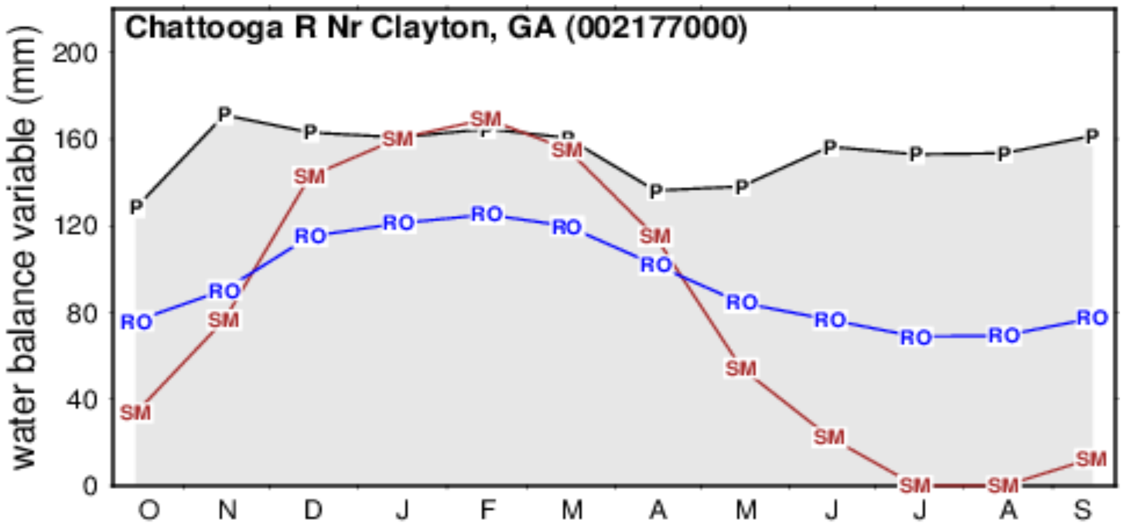
Hydrological Prediction: How well can we estimate catchment dynamics?

- Accuracy in precipitation and temperature estimates
- Fidelity of hydrology models – process/structure
- Effectiveness of hydrologic data assimilation methods

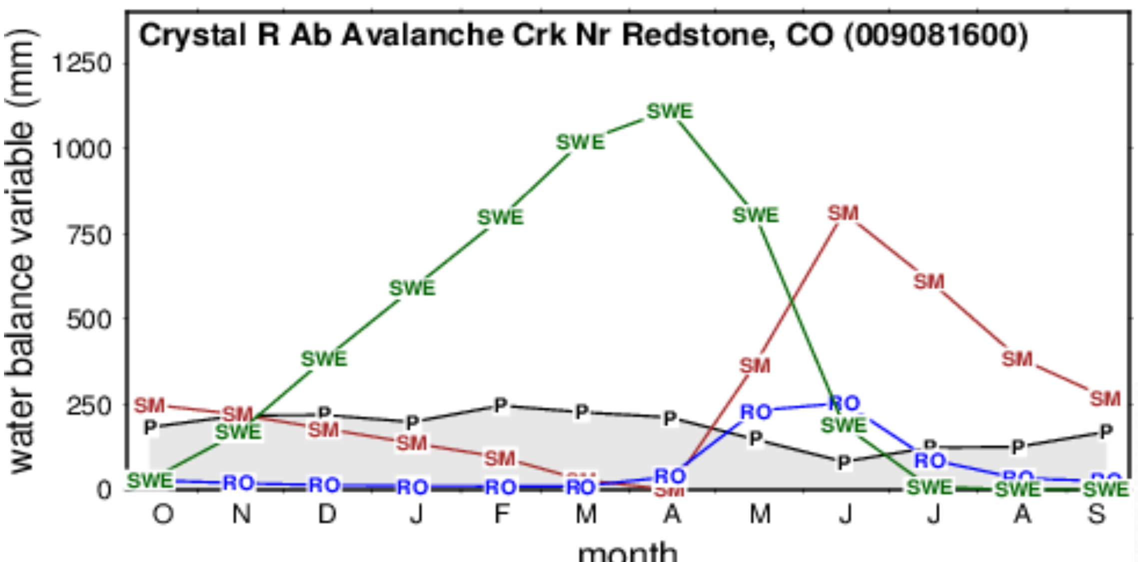
Atmospheric predictability: How well can we forecast the weather and climate?

Opportunities: How do these areas influence variability informing different water applications?

Hydro-climatic/Seasonal Variation in Watershed Moisture



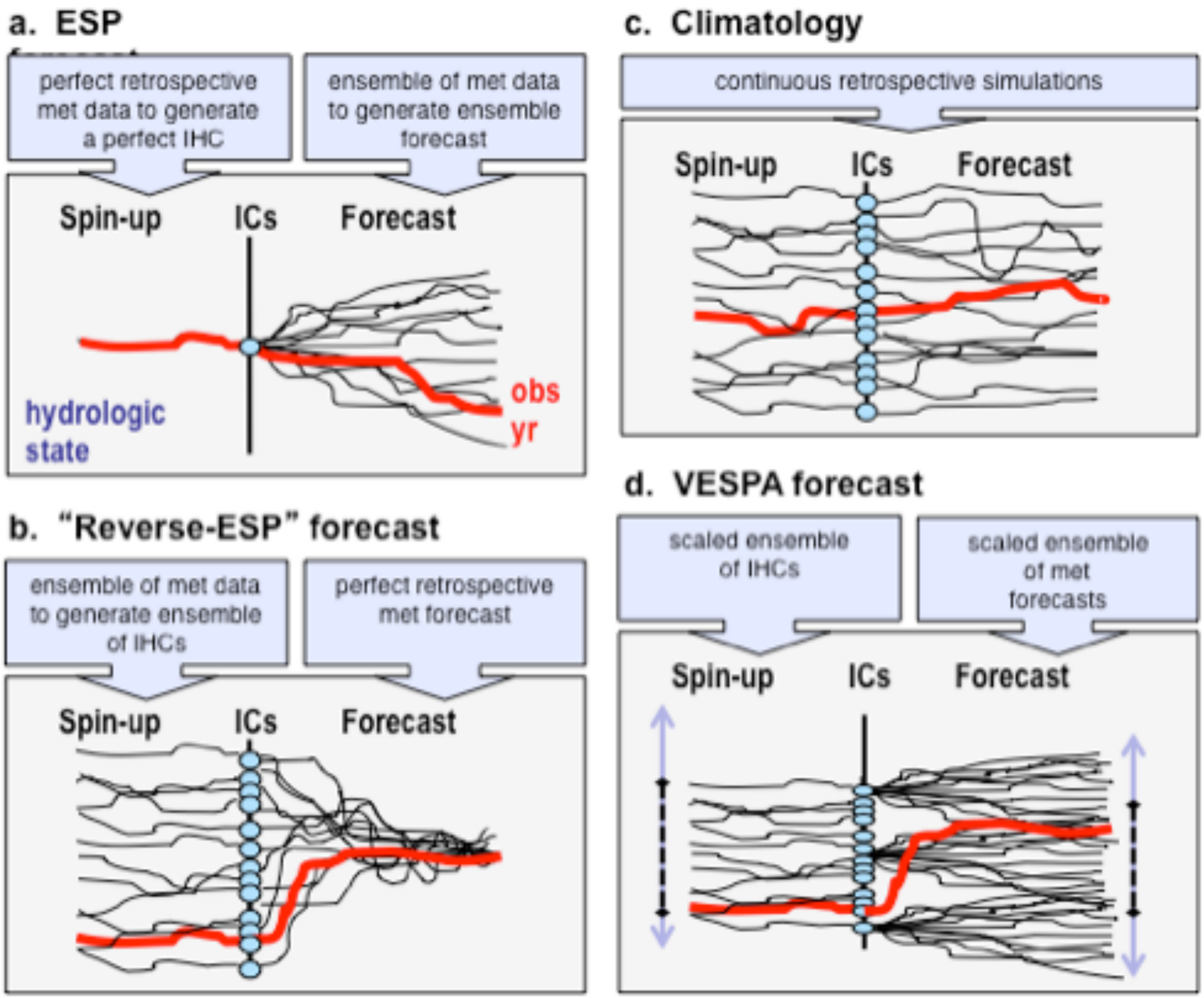
- humid basin
- uniform rainfall
- no snow
- small cycle driven by ET



- cold basin
- drier summers
- deep snow
- large seasonal cycle
- April snowmelt dominates May-June runoff

Assessing the sources of flow forecast skill

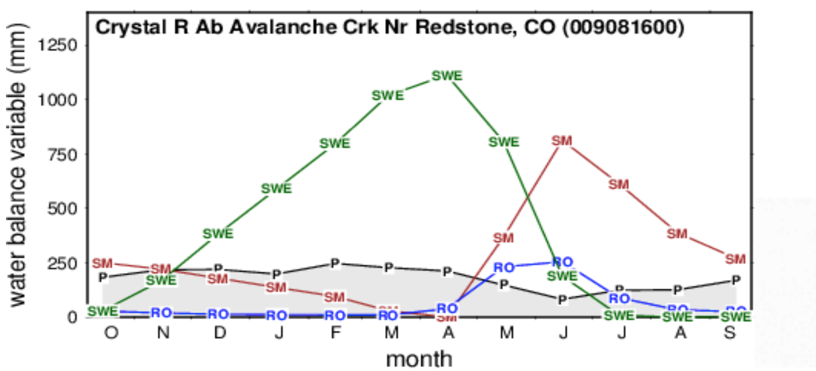
vary predictor uncertainty → measure streamflow forecast uncertainty



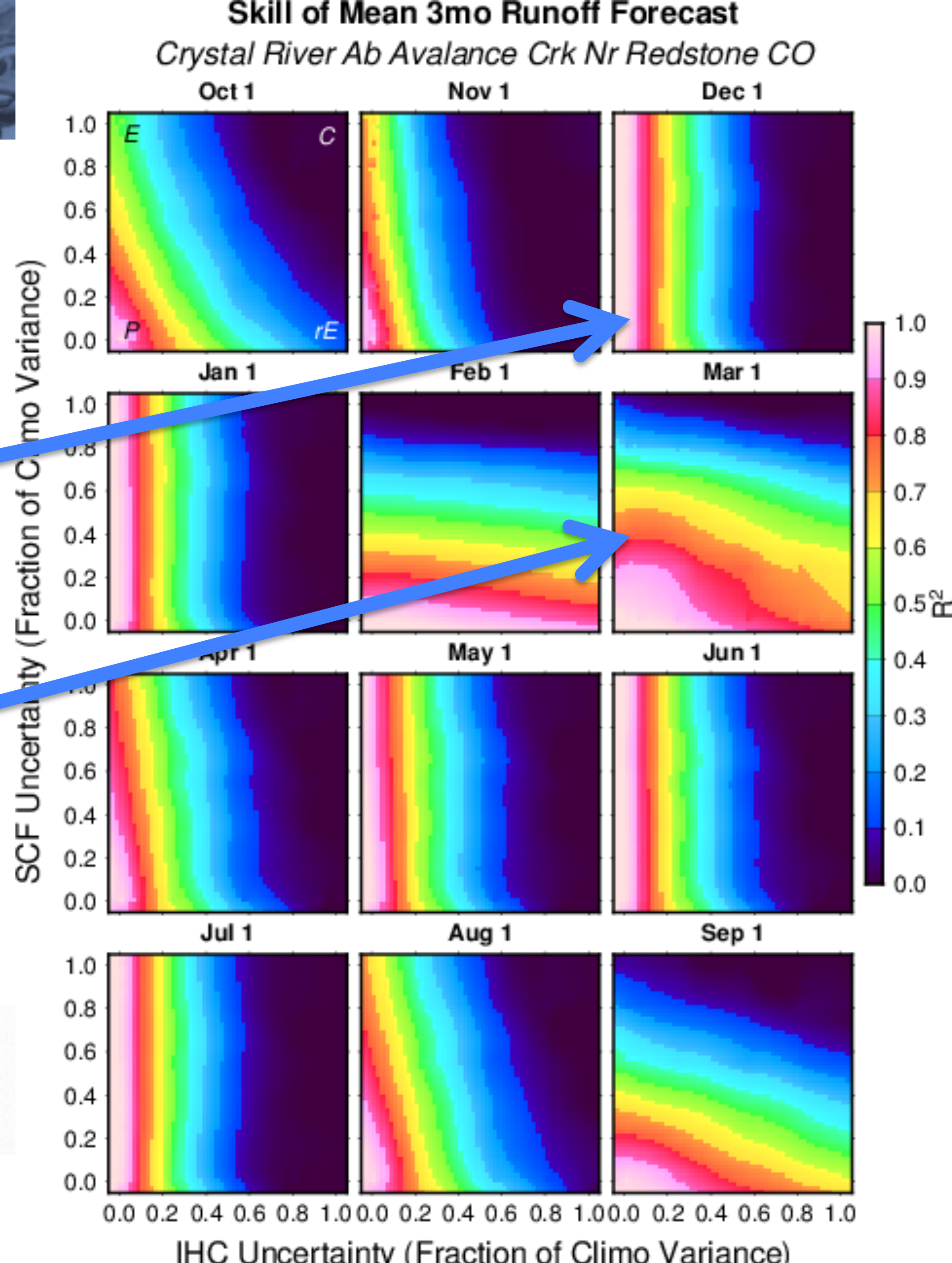
Wood et al, JHM 2014 (submitted)

Snow-Driven Basin in the Western US

- Wide seasonal variations in influence of different skill sources
- cold forecast period (Dec-Feb) -- forecast skill depends mainly on initial condition accuracy
- warmer snowmelt forecast period forecast skill depends strongly on met. forecast skill

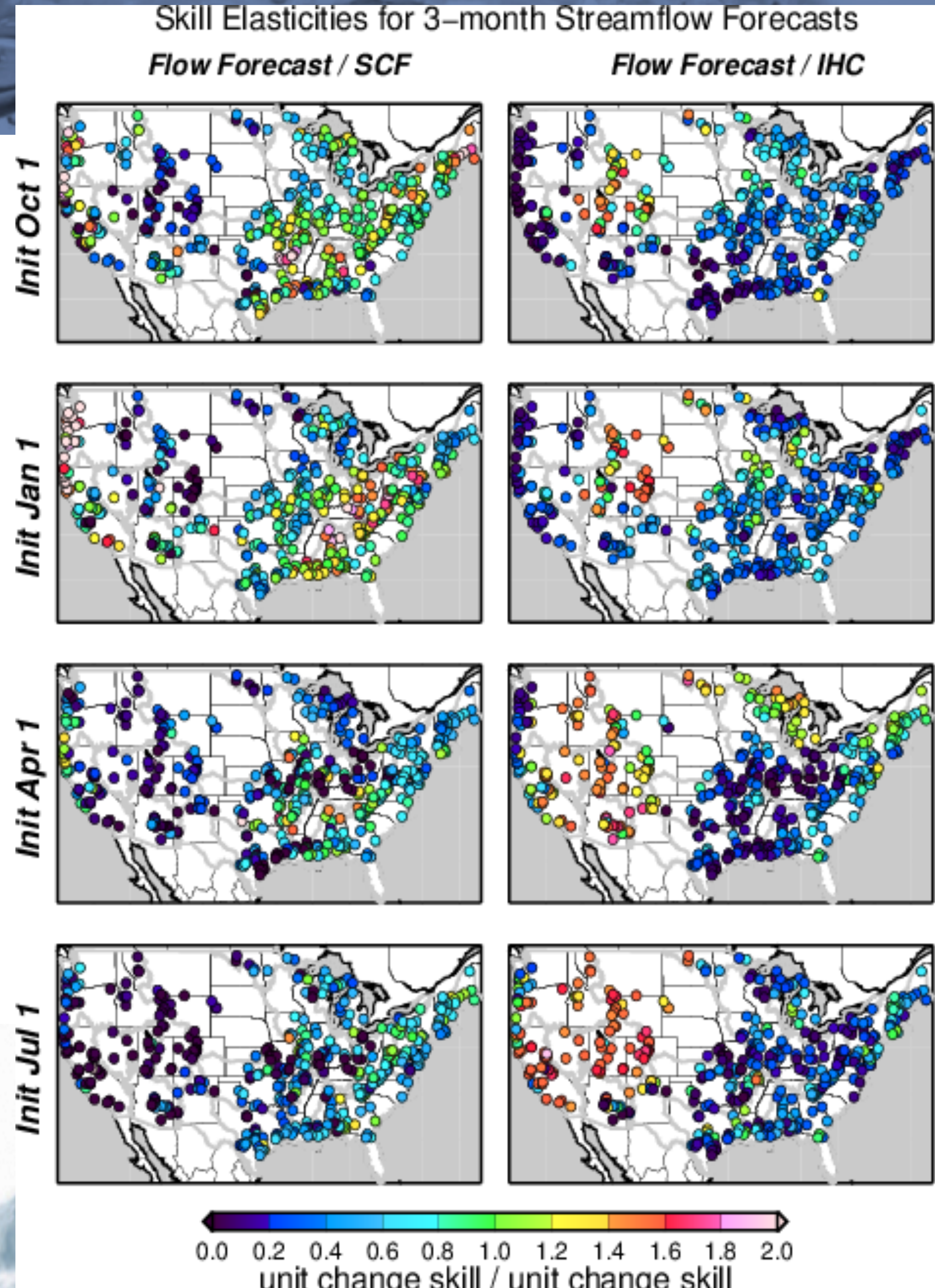


IHC: initial Hydrologic Conditions
SCF: Seasonal Climate Forecasts



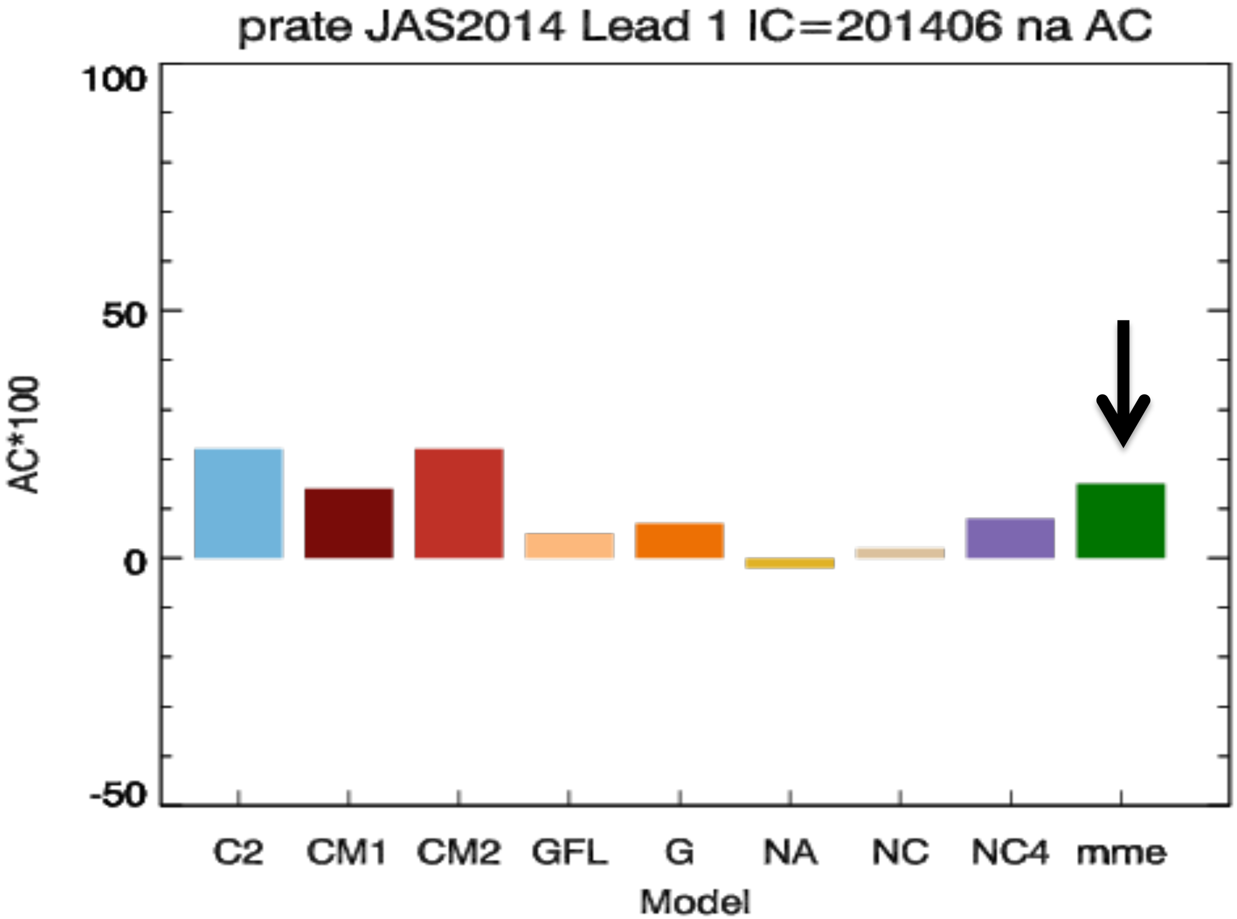
Flow Forecast Skill Elasticities

- The % change in flow forecast skill versus per % change in predictor source skill
- Can help estimate the benefits of effort to improve forecasts in each area
- This research is funded by water management agencies – Reclamation and US Army Corps of Engineers



North American Multi-Model Ensemble at NOAA

The NMME is the latest/greatest effort at climate prediction from N.A.:
- models vary in skill each month, and by region



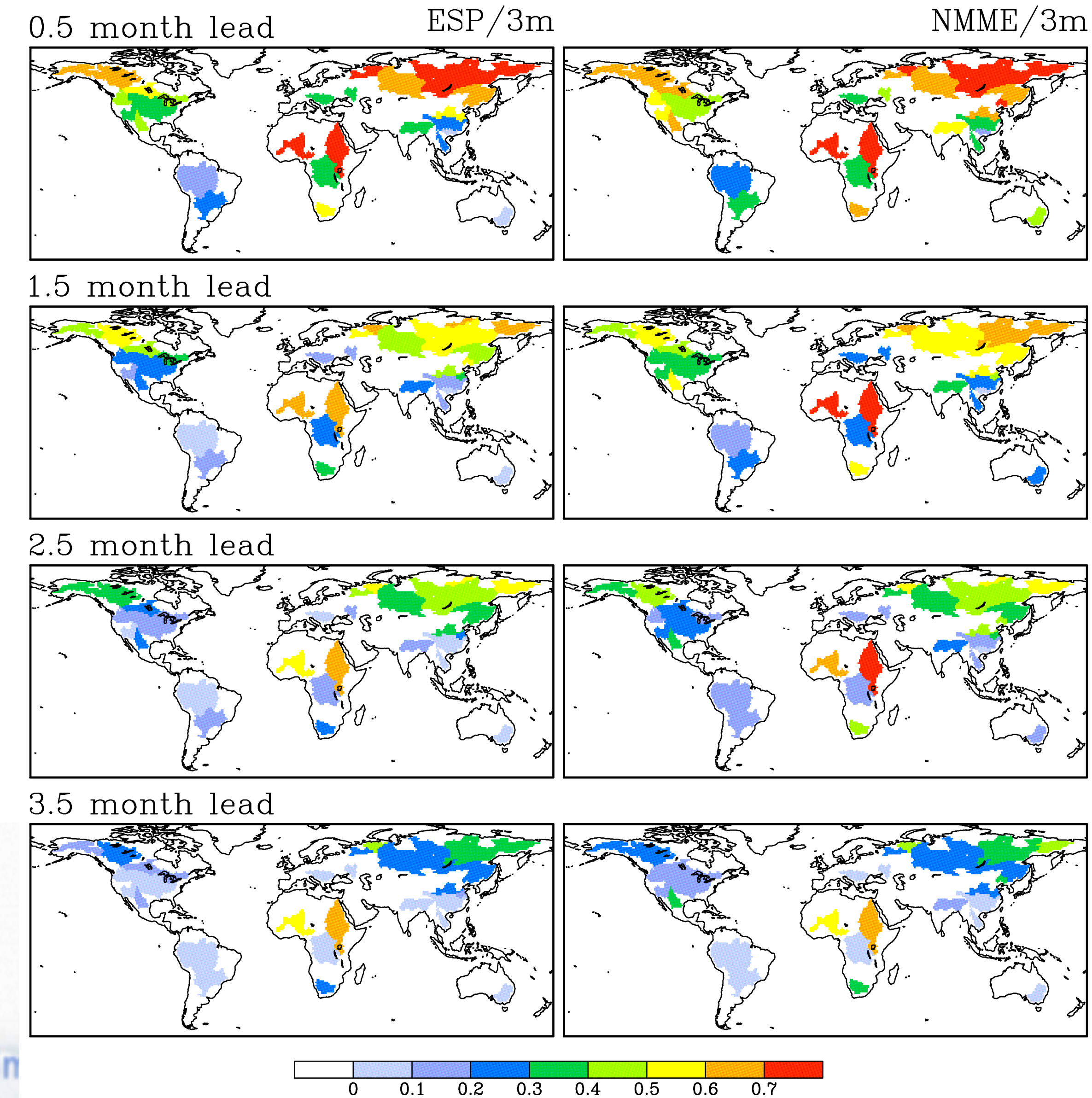
GEWEX Seasonal Forecast Research Examples

There is a large-scale GEWEX-supported line of seasonal hydrologic prediction work.

- Less connected with users, looking at underlying science issues.
- A popular target application is drought monitoring/prediction.

Eric Wood has just completed an assessment of using National Multi-model Ensemble climate prediction in hydrologic LSMs for RHP basin seasonal prediction. (accepted in BAMS, Xin et al, 2015)

From: Eric Wood   Hit Rate for Drought Prediction

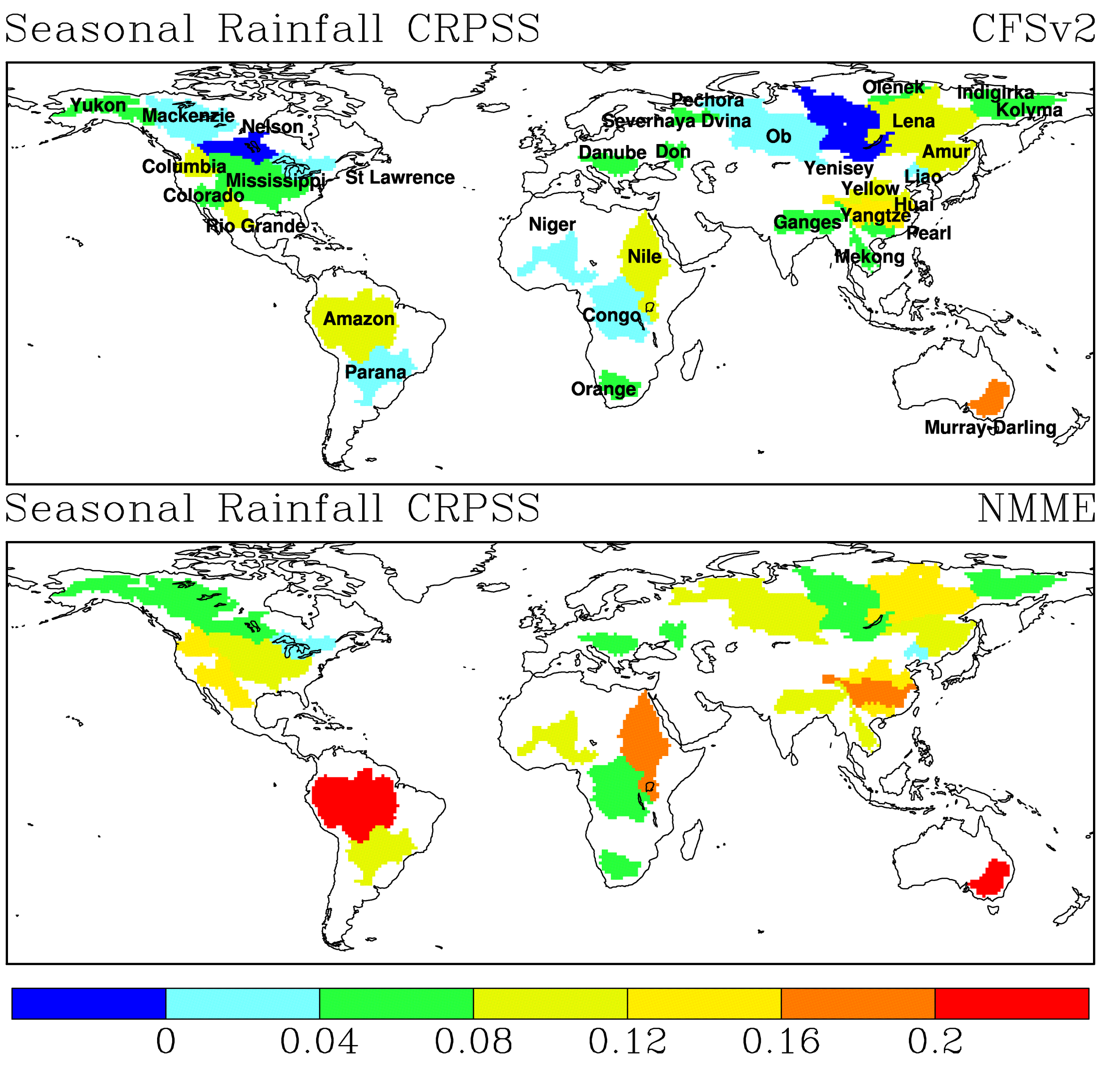


Hydrologic Ensemble Prediction EXperin

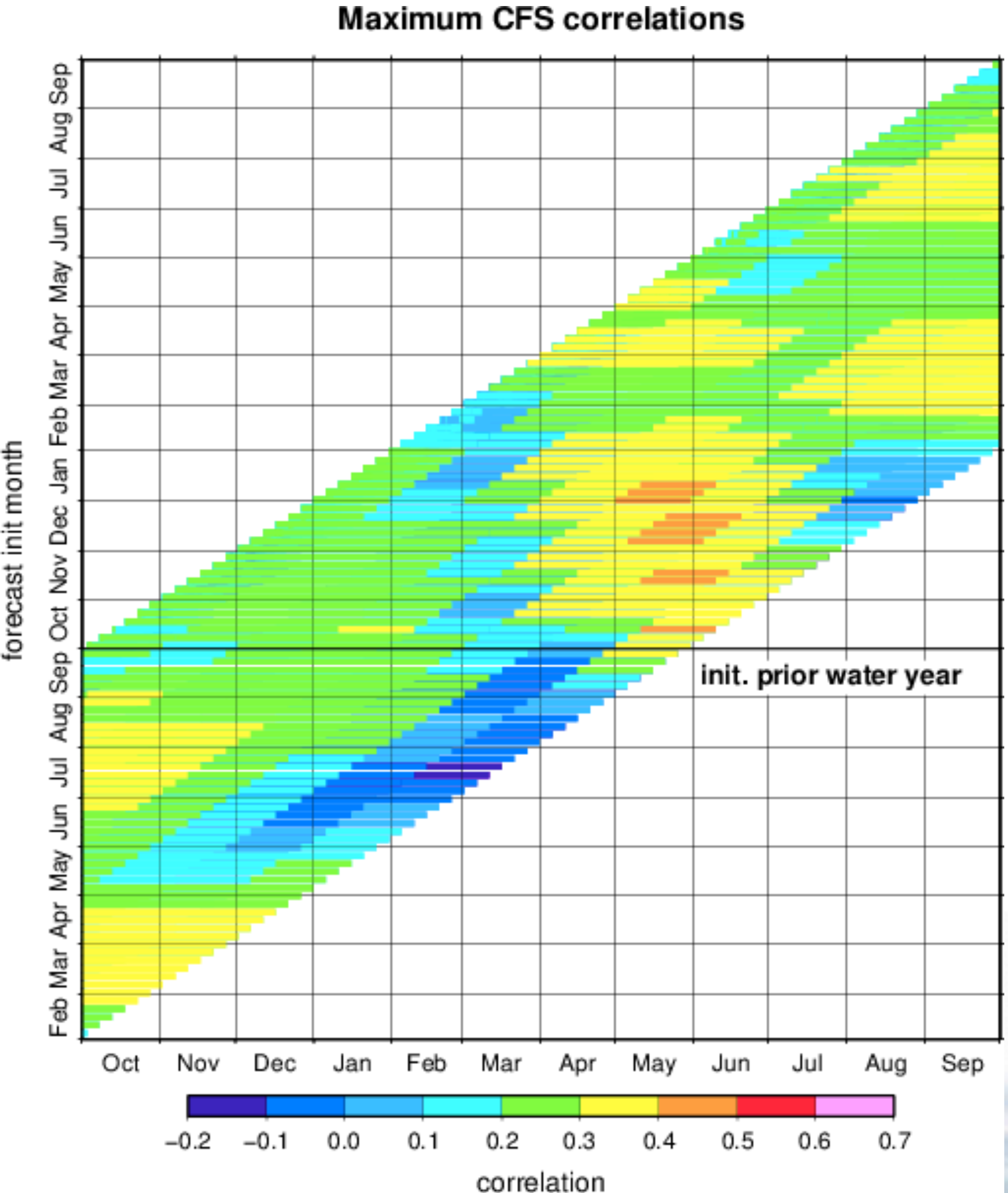
GEWEX Seasonal Forecast Research Examples

Eric Wood's NMME climate prediction in hydrologic LSMs for RHP basin seasonal prediction.
(accepted in BAMS, Xin et al, 2015)

- Rainfall skill

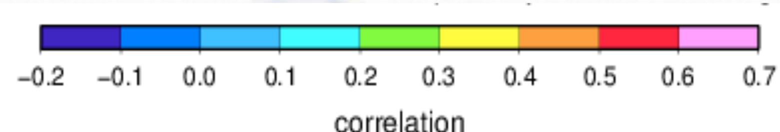


Individual model prediction skill varies



- For seasonal time scales, precipitation skill varies from poor to moderate
  - depends on season and lead time
  - depends on location
  - may depend on large-scale ‘climate state/ regime’

East R at Almont, Co, precip (very difficult location)



The urgency of understanding predictability

teleSUR

Article

Dec 8, 2014

NEWS VIDEOS MULTIMEDIA OPINION BLOGS ANALYSIS YOU'RE THE REPORTER PROGRAMS

AGENDA | Human Rights Day | CIA Torture | Battling for Climate Justice | US Resists Police Racism

News > Latin America

Drought-Hit Sao Paulo Has Two Months of Water Left

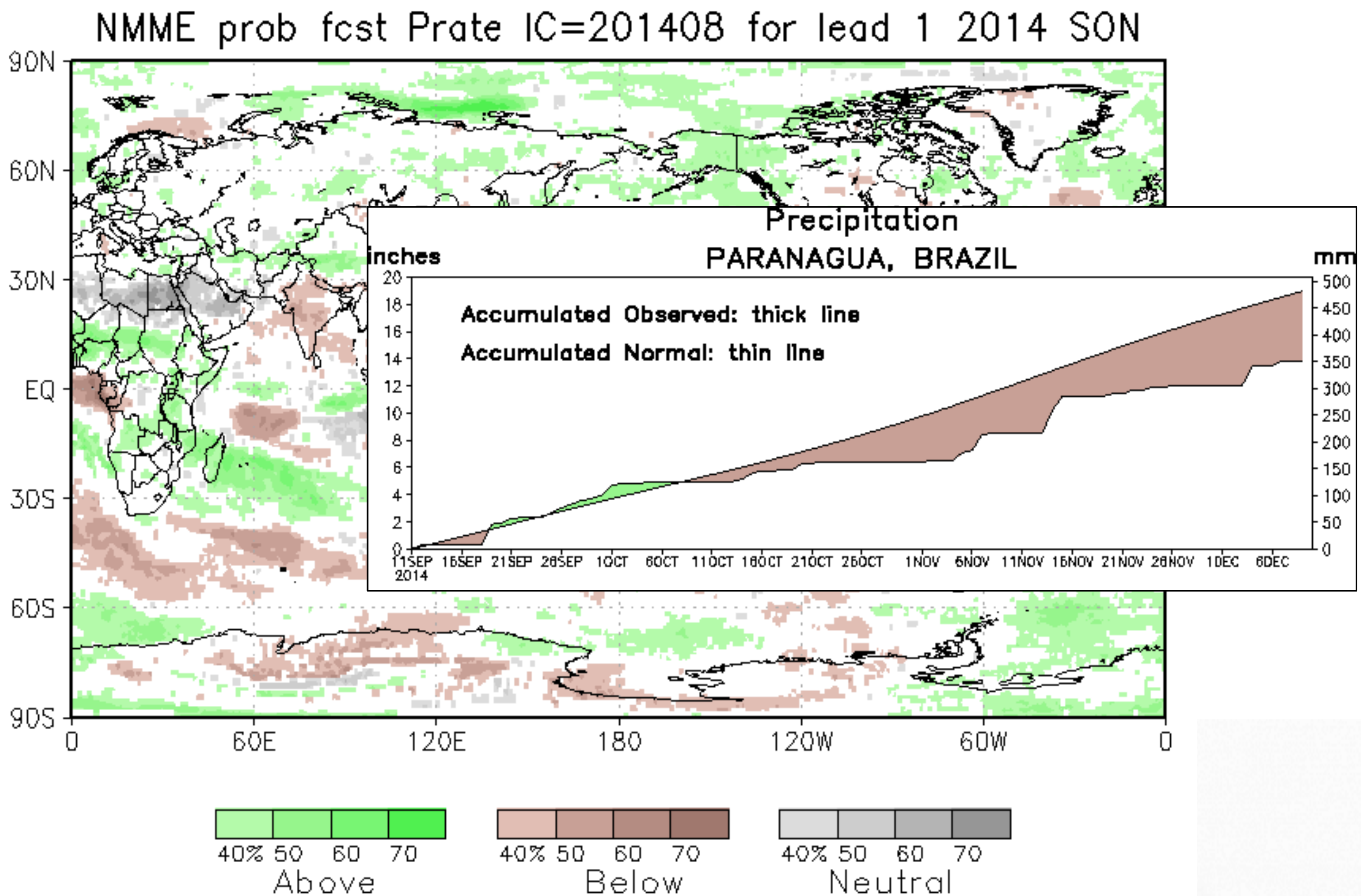
A man looks at the cracked ground of Jaguari dam, part of the Cantareira reservoir in Sao Paulo state, showing record low water levels January 31, 2014. (Photo: Reuters) | Photo: Reuters

Published 8 December 2014

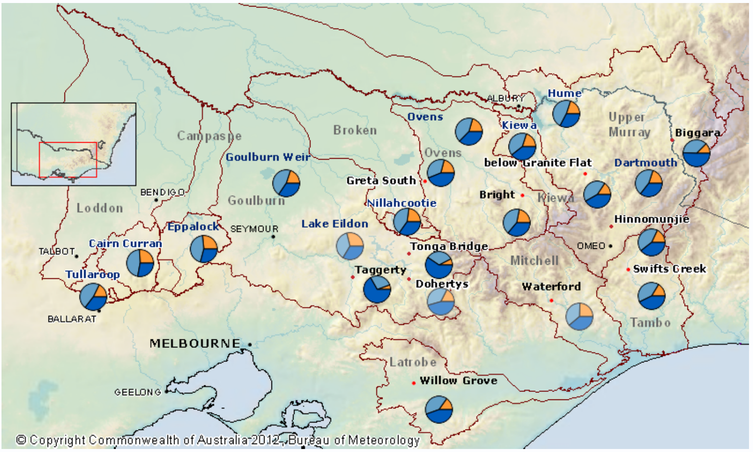
The emergency reserves should last for two months, but water use is also expected to increase during the holiday season.

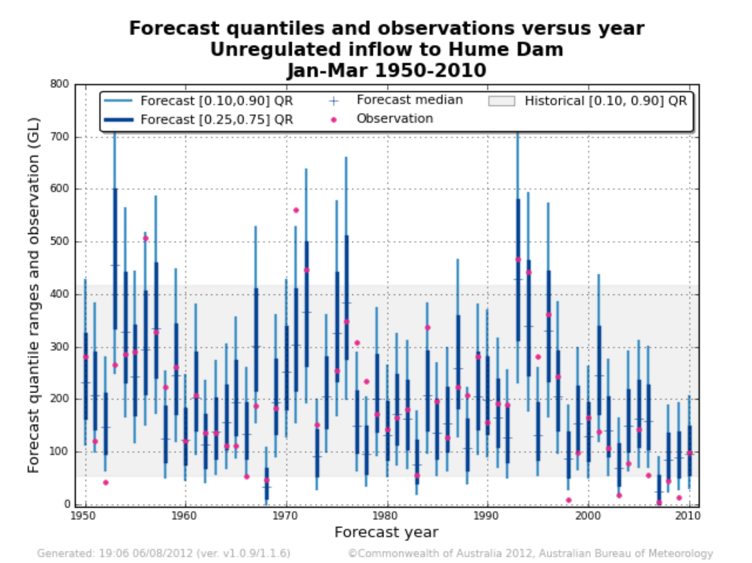
The urgency of understanding predictability

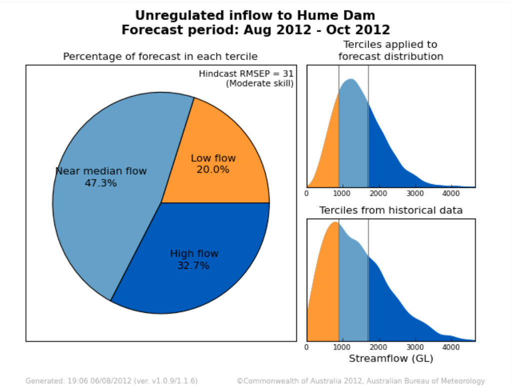
NMME forecast for precip (terciles)

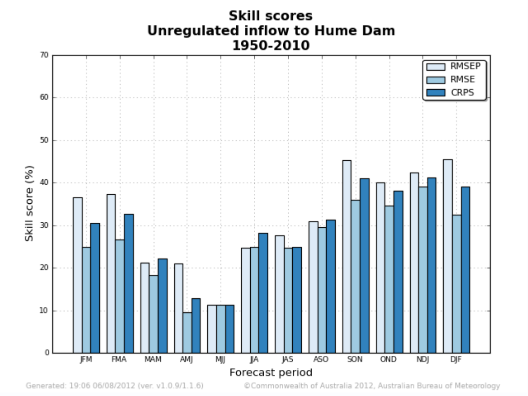


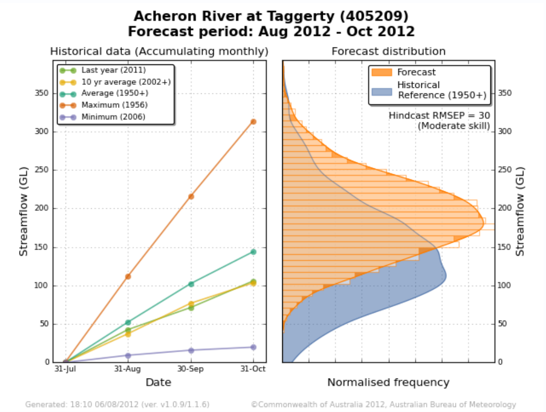
AU Seasonal streamflow forecasting: dynamical-statistical











QJ Wang, CSIRO http://www.bom.gov.au/water/ssf/

Efficiency – Complexity Tradeoff

- **A number of forecasting centers around the world have offered seasonal streamflow predictions for decades (over 8 in the US, for instance).**
  - Other countries/agencies are interested in starting such services.
- **The approaches span a wide range of data requirements & complexity. From simplest to most complex (light to heavy data lift):**

a. regression of flow on in situ obs (rainfall, SWE, flow)
   - 'regression' = regressive technique, ie PCR, MLR, etc.

b. the same but with teleconnection indices included as predictors

c. the same but with custom climate state predictors (eg EOFs of SST) or climate forecasts

d. land model based ensemble simulation (eg ESP or HEPS) without climate forecast
   - possibly with short to medium range prediction embedded

e. climate index (or custom index) weighted ESP

f. climate forecast weighted ESP (eg using CFSv2 or NMME in the US)

g. climate forecast downscaled outputs with weather generation for land model ESP/HEPS
   - from one land/climate model or multi-model; from simple land model to hyper-resolution

h. d-g with statistical post-processing to correct model bias

i. d-g with post-processing to correct bias and merge with other predictions (cf BOM approach)

j. d-g with DA to correct land model errors (particularly with snow variables)

k. d-g with both post-processing AND DA

↕ simple statistical approaches can be viewed as benchmark for dynamical approaches

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Relationship between GHP and HEPEX

A common motivation:

the existence and impacts of floods and droughts

RHPs

Improving scientific understanding of regionally significant features water & energy cycle, leading to:

- Better models
- Better datasets

→

HEPEX

Applying improved scientific understanding, data and models to improve operational prediction of floods and droughts

→

Prediction Applications

HEPEX methods filtering into operations for

- Water/energy management
- Hazard mitigation

←

Applications motivate & inform the research

- **tighten focus**
- **change level of scrutiny**

R2O/O2R – an arduous trek requiring tradeoffs

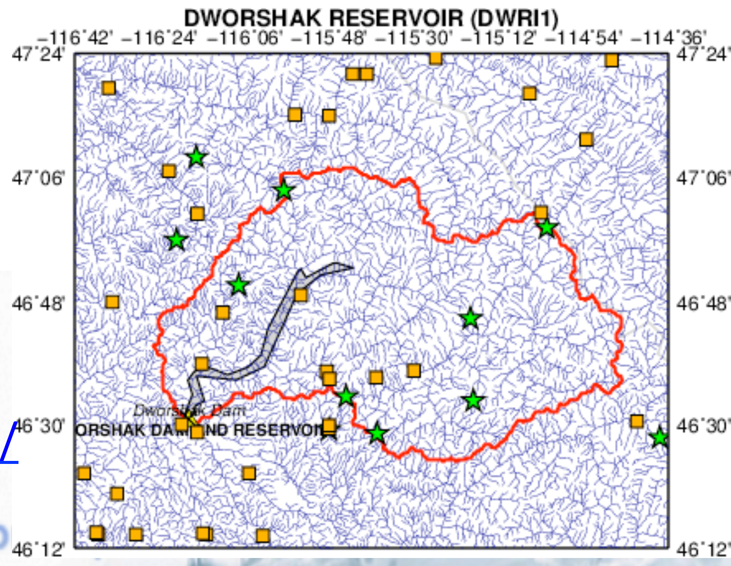
How could a cross-cut project help strengthen the relevance of research to applications?

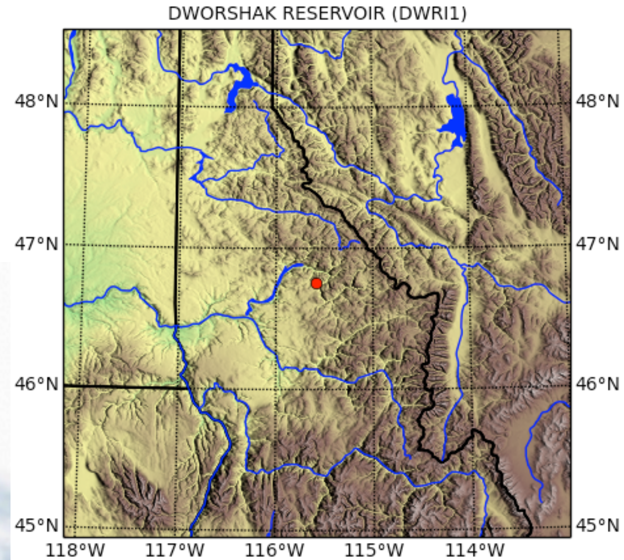
Seasonal Forecasting Cross-cut Project Concepts

Possible thrusts

1. GEWEX-ish: Science-oriented exploration of seasonal climate and hydrologic predictability from state-of-the-art datasets and models in RCP/RHP study domains. - Eric Wood would lead

2. HEPEX-ish: How well do methods across the statistical-dynamical spectrum harness local-to-regional scale hydrometeorological predictability – for a basin collection determined from water resources considerations. - Andy Wood / HEPEX would lead





http://www.ral.ucar.edu/staff/wood/case_studies/

Experimental Outline

1. Set leads/participants (solicit through HEPEX & GHPs)
2. Coordinate:
   - define study basins
   - protocol for evaluation
   - scope/timeline of experiments
3. *Assemble data, models, methods*
4. Predictability Experiments
   - What sources of predictability dominate seasonally, for various leads & predictands, locations, variables?
   - Where are the greatest uncertainties / weaknesses and scientific limits?
5. Approach Intercomparisons
   - What is the marginal benefit of dynamical approaches over statistical ones for various types of prediction? Where are dynamics necessary?
6. Dissemination / Outreach
   - Website key, publication, also local interaction with users

Relevant Recent & Future Events

Recent

- BfG (Koblenz) hosted a recent meeting on seasonal forecasting for water management
  - will lead to a Guidelines document for WMO on Seasonal Prediction (led by Jan Danhelka, CHMI).
  - http://www.bafg.de/DE/05_Wissen/02_Veranst/2014_10_15.html

Future

- HEPEX Seasonal Forecast Meeting hosted by SMHI, Sweden, September 2015
- Summer short course on Seasonal Forecasting?
- ***Seas. Climate/Hydrology Ensemble Prediction Experiment (SCHEPEX …)?***

HEPEX

Hydrologic Ensemble Prediction EXperiment

Questions?

Applications and Elements

QJ Wang, CSIRO

- **Multiple statistical models**
  [Schepen, Wang & Robertson – JCLI 2012], [Wang, Schepen & Robertson – JCLI 2012]
- **Combining statistical and dynamical models**
  [Schepen, Wang & Robertson – JGR in press]
- **GCM calibration, bridging and merging**
  [Schepen, Wang & Robertson – JCLI in review]
- **Combining multiple GCMs**
  [Schepen & Wang – MWR in review]
- **Forecasting monthly rainfalls to long lead times**
  [Hawthorne, Wang, Schepen & Robertson – WRR in review]
- **Forecasting seasonal rainfall across China**
  [Peng, Wang, Bennett, Pokhrel & Wang – JOH in review]
- **Forecasting seasonal temperature**
- **Forecasting Hydrology / Streamflow**