Climate Data for CVHM

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USGS

U.S. Bureau of Reclamation
Central Valley Hydrologic Modeling Workshop
Sacramento, California
January 18, 2012

Today's Presentation

Climate Background

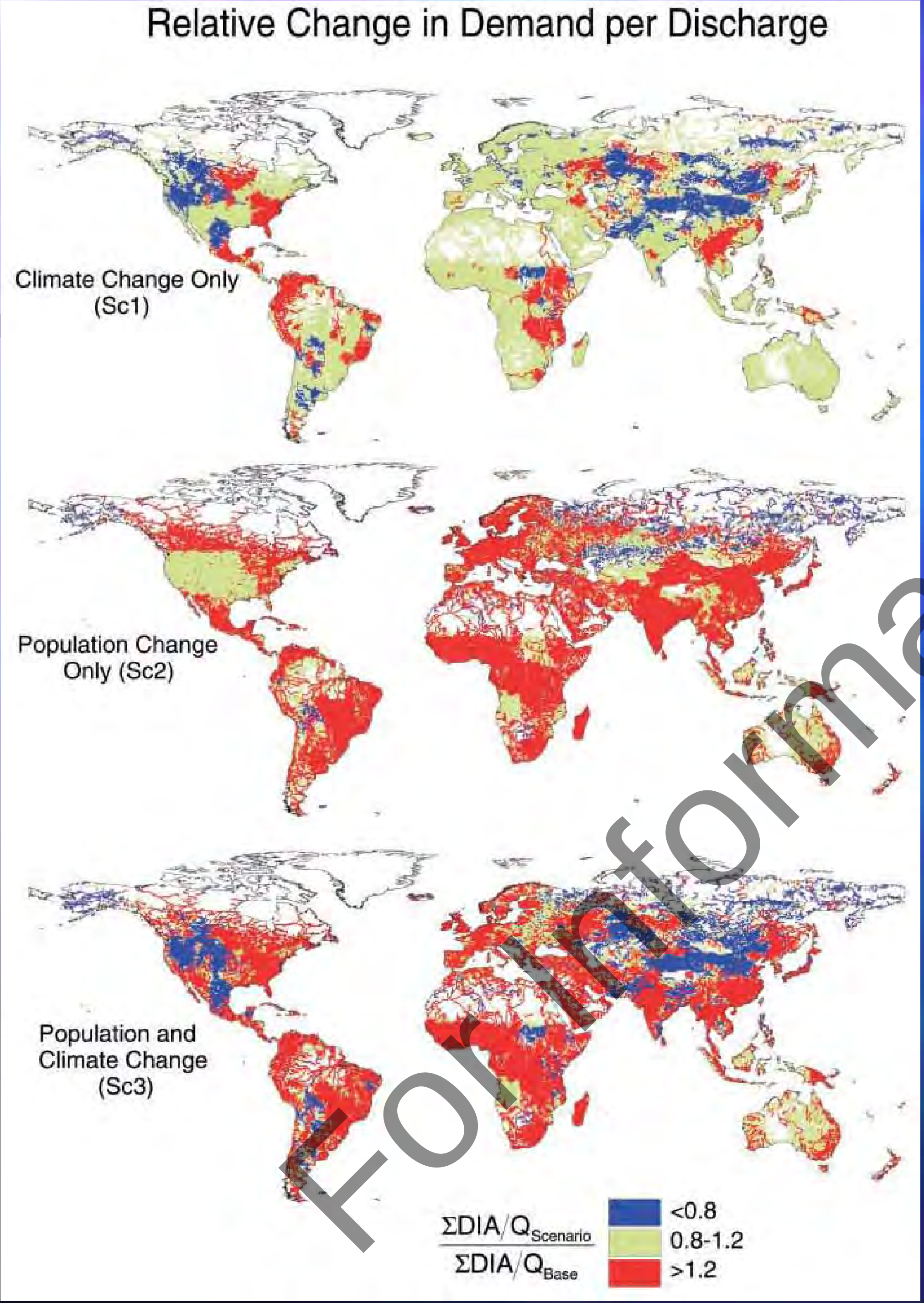
Precipitation

Evapotranspiration

Scripts/Tools

Climate Analysis

USGS

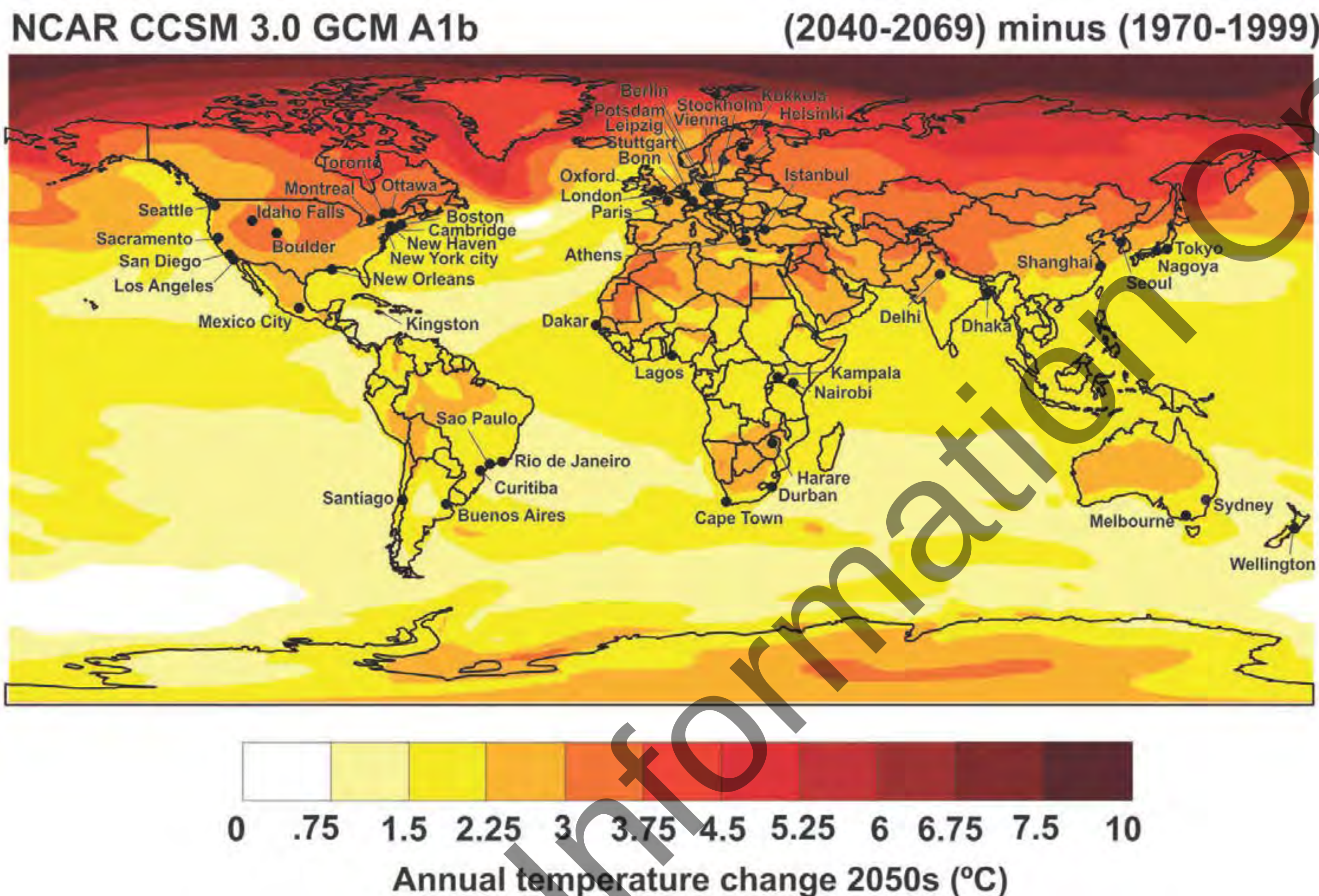


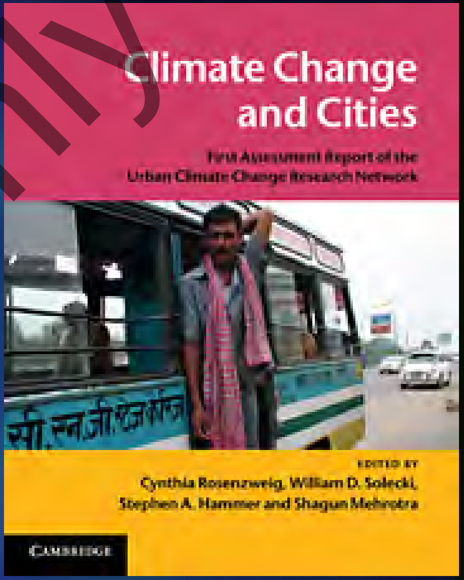
Global Analysis of Water Stress from Major Surface-water Drainages

- **Large part of World's Population with Water Stress**
- **Rising Water Demands outweigh effects of greenhouse warming-climate change through 2025**
- **Direct human impacts on global water supply poorly articulated but important to larger global change question**

(Vorosmarty et al., April, 2010, Science)

Additional Urban-Demand and Climate-Change Issues





Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network (Cambridge University Press) **http://www.cambridge.org/us/catalogue**

Risk Framework

- **Climate Hazards**
- **Vulnerabilities**
- **Adaptive Capacity**
- **Sustainability**

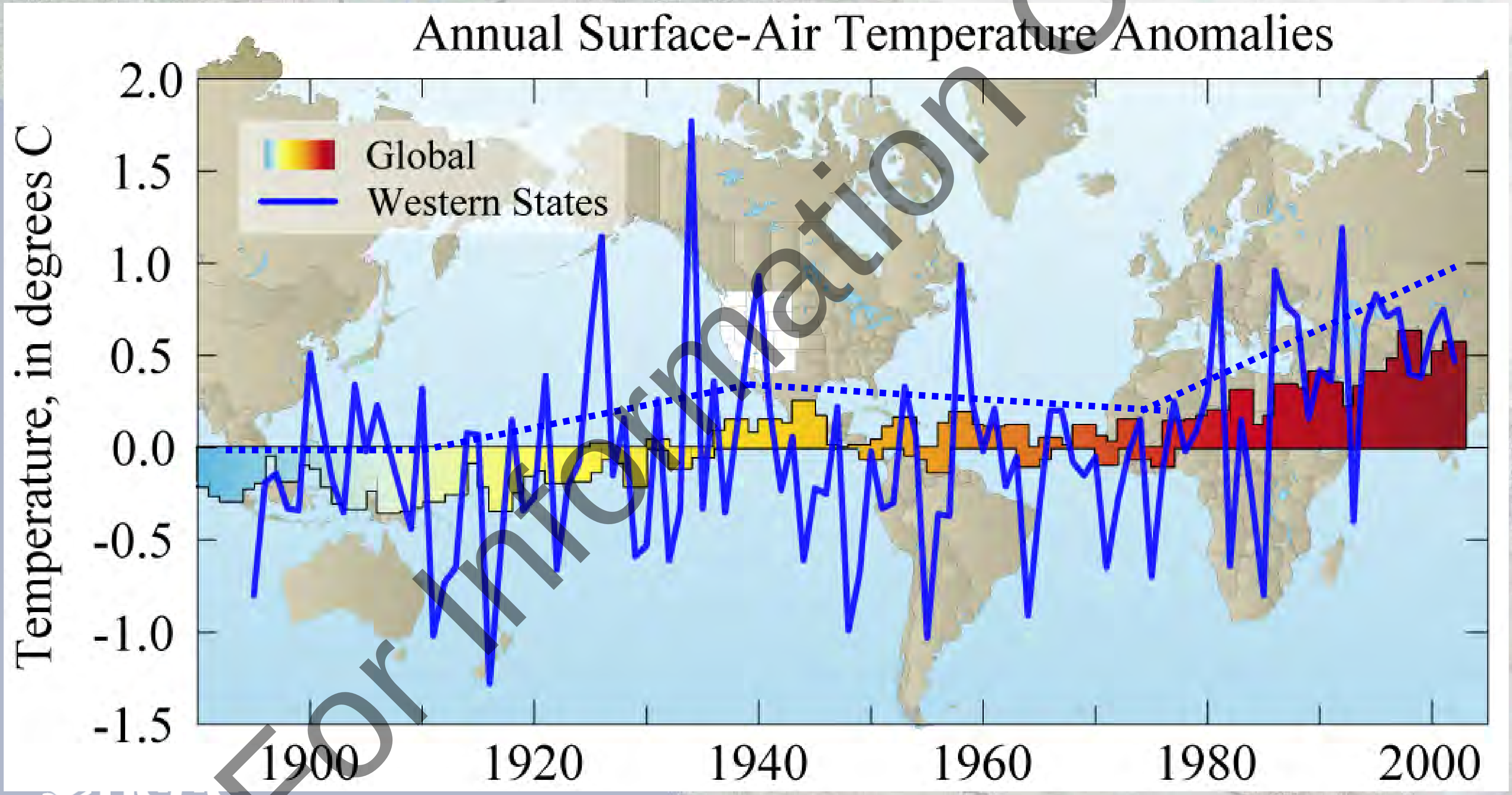
Urban Climate → ***Urban Heat Islands, Air pollution & Climate extremes***

Governance/Management → ***Transboundary, Capture of Unappropriated Runoff & Environmental Flows 1st***

Managed Resources → ***Agriculture to Urban, Water-Energy Nexus, & Formal vs Informal Supply***

1. Review of recent trends & projections:

The western states have been warming in recent decades.



USGS

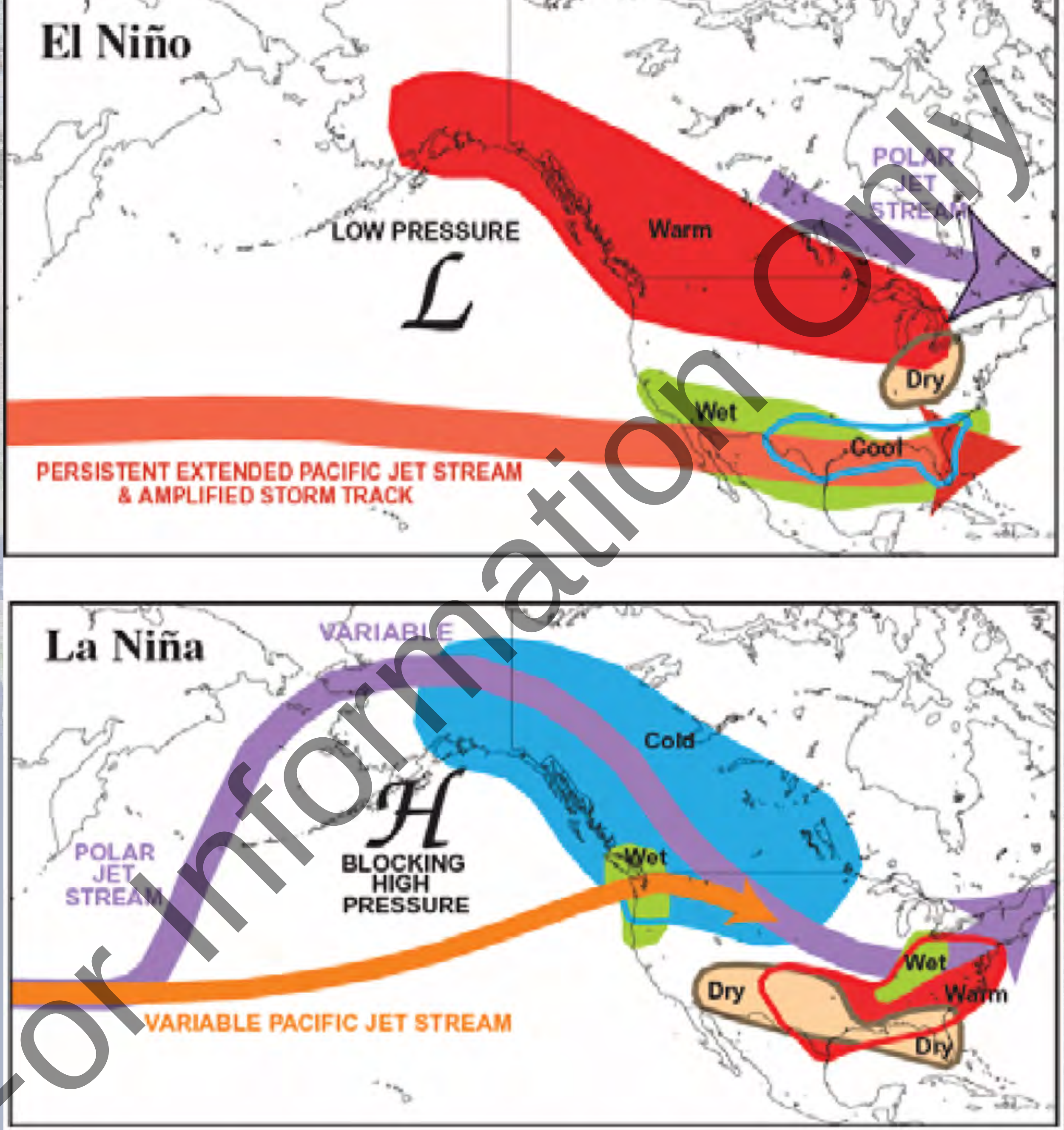


Figure 2. Typical winter-time weather anomalies and atmospheric circulations during moderate to strong El Nino and La Nina events, depicting the generalized warm/wet and cool/dry

RELATION TO USGS MISSIONS
SUSTAINABILITY/CONJUNCTIVE USE CENTRAL VALLEY

- **One Water → Single resource (Precipitation, surface water and groundwater)**
- **Competition for Water → Demand for water resources People, Agriculture Environment (Entire Central Valley not just Sacramento and San Joaquin)**
- **Sustainable development → Complex system requires integrated water-management approach → Linked models used to support this analysis**
- **Availability/Sustainability→ Changes in streamflow, groundwater storage, regions suitable for agriculture, and dynamics between natural and societal water-supply demands**
- **Groundwater effects → Significant changes in Flows, Storage, & Secondary effects on multiple time scales (Flow-centric & Storage-centric Indicators?)**
- **Climate variability/change Analysis → Management provided with observationally informed modeling and resource analyses**
- **Climate change → Important influences on management strategies for conjunctive/sustainable use on periods of 100 years or more (ENSO, NAMS/PineappleExp, PDO, AMO, + Change)**

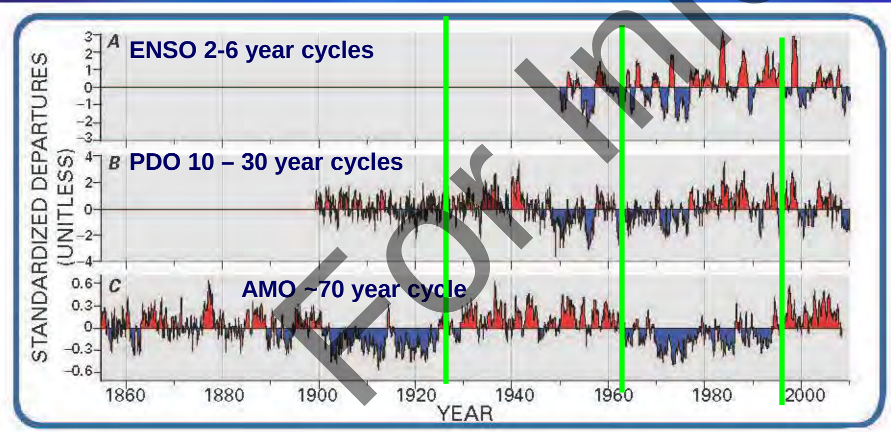


Figure 1. Interactions between the positive (red) and negative (blue) phases of the (*A*) multivariate El Niño/Southern Oscillation (ENSO) index (Wolter and Timlin, 1993, 1998), (*B*) Pacific Decadal Oscillation (PDO) index (Mantua and Hare, 2002), and (*C*) Atlantic Multidecadal Oscillation (AMO) index (Enfield and others, 2001) cumulatively affect U.S. climate and, in turn, surface and groundwater resources.

USGS Office of Global Change
Effects of Climate Variability and Change on Groundwater Resources of the United States
Fact Sheet FS09-3074 (2009)
By Jason Gurdak, Randall T. Hanson, and Timothy R. Green

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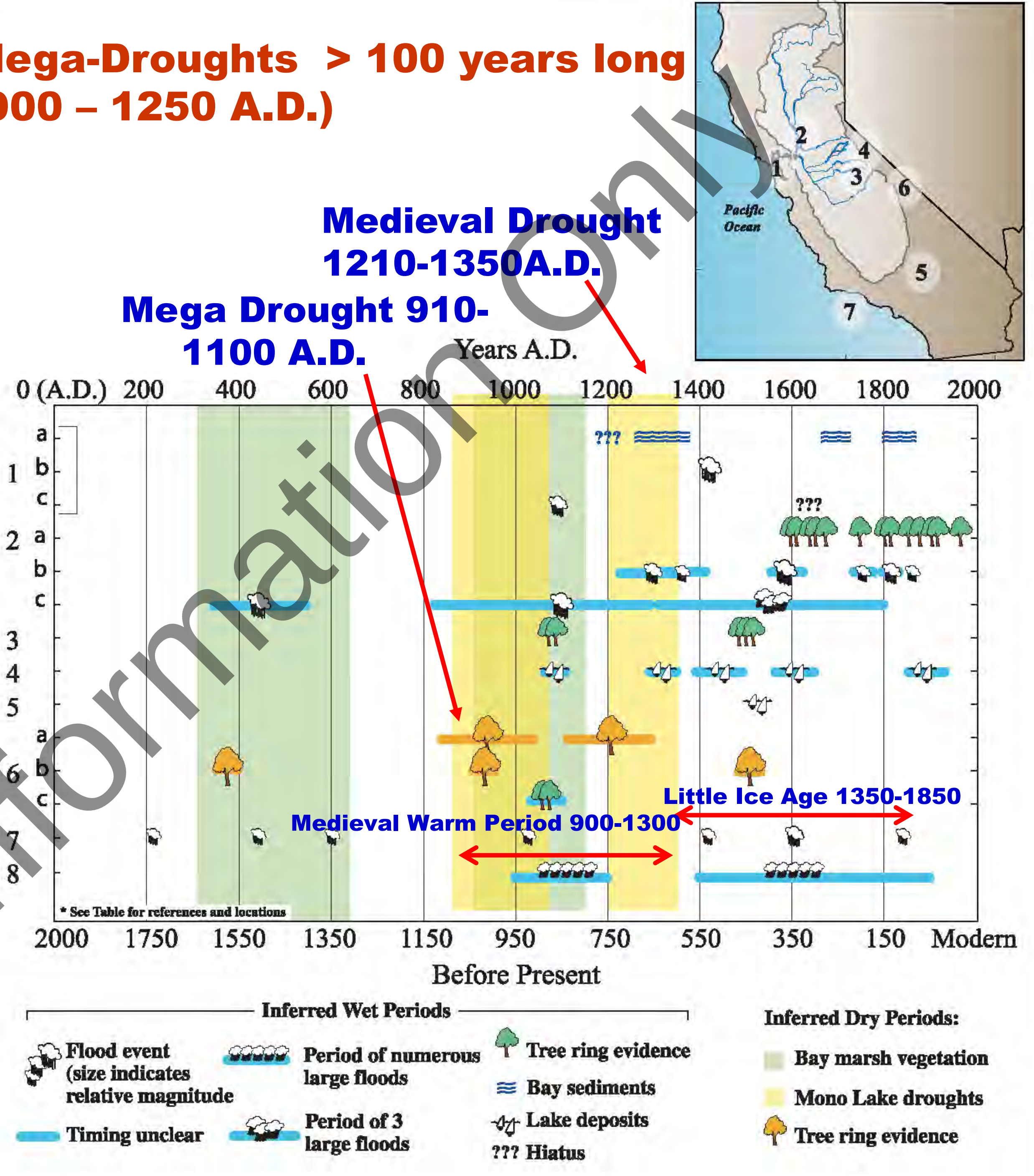
Paleo-Extreme Climate Events Central Valley, California

Is one person's Climate Change another person's Climate Variability??

NO--There are natural & anthropogenic components & competing drivers such as urbanization

Modified from "Holocene climates and connections between the San Francisco Bay estuary and its watershed--A review", by Malamud-Roam, Dettinger, Ingram, Hughes, and Florsheim, 2007, San Francisco Estuary and Watershed Science, 28p.

Mega-Droughts > 100 years long (900 – 1250 A.D.)



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How Conjunctive Use/Sustainability Analysis Help Stakeholders?

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- **Climate Vulnerabilities?** → Extreme Events, Sustained Events, Permanent changes to system, Unsustainable adaptation

  Primary Effects → More dry Springs, Higher minimum temperatures, More cloudy/foggy days, More windy days, Amount/timing of snowmelt runoff, Frequency of wet years, Frequency of storms, Length of growing seasons, etc.

  Secondary Effects → Land Subsidence, Seawater intrusion, Decreased streamflow gains/losses, Increased soil salinization, Decreased soil moisture, Land-use adaptation (*esp. urbanization!*)

- **Variables/metrics used for vulnerabilities?** Focus of current research and analysis of coupled models -- most "Indicators" only based on data. Need to make decisions on indicators from data and physically-based models.

- **Ensemble Analysis Adequate?** Maybe not -- the traditional statistical and probabilistic approach to synthesis of results may not capture linkages or secondary-limiting factors of conjunctive use. Indicators from ensembes may not catch extremes or tipping points

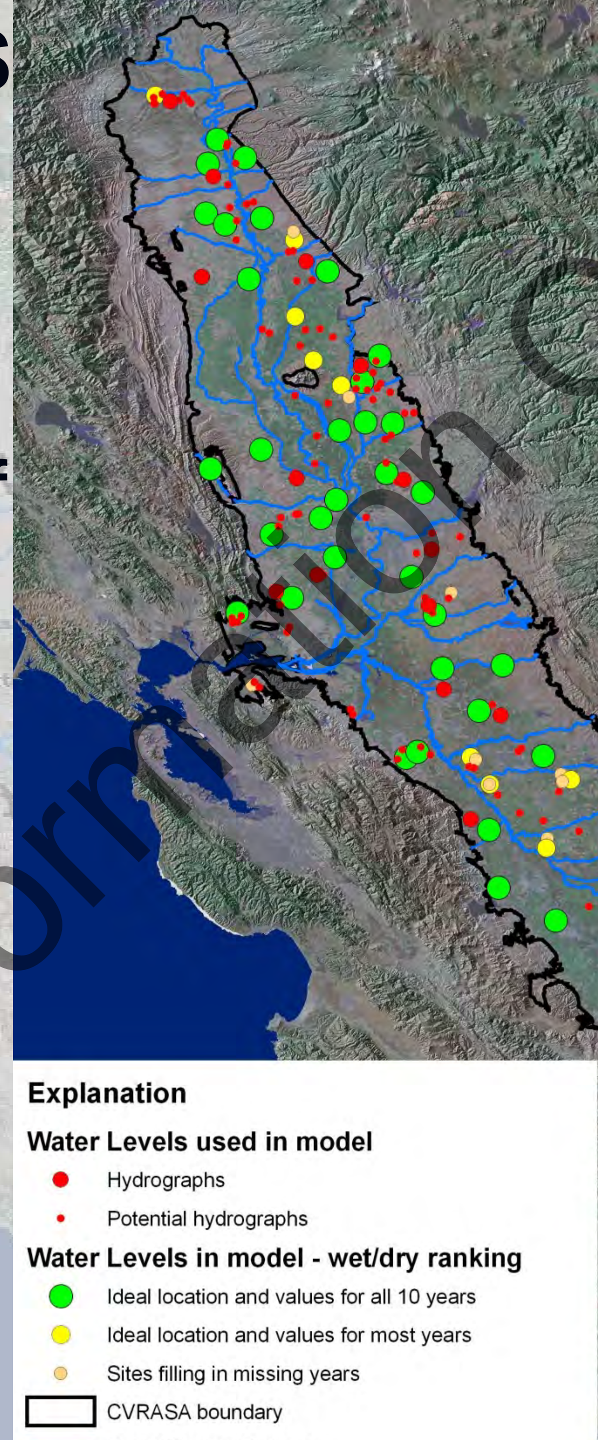
- **Current Observational Networks & Assoc Data Adequate? Maintenance of Input Data Streams for regional hydrologic models one of biggest challenges and needs** → Part of DSS should include integrated ground and remote-sensing networks in Mountains & Valleys→ Support of SELF-UPDATING MODELS

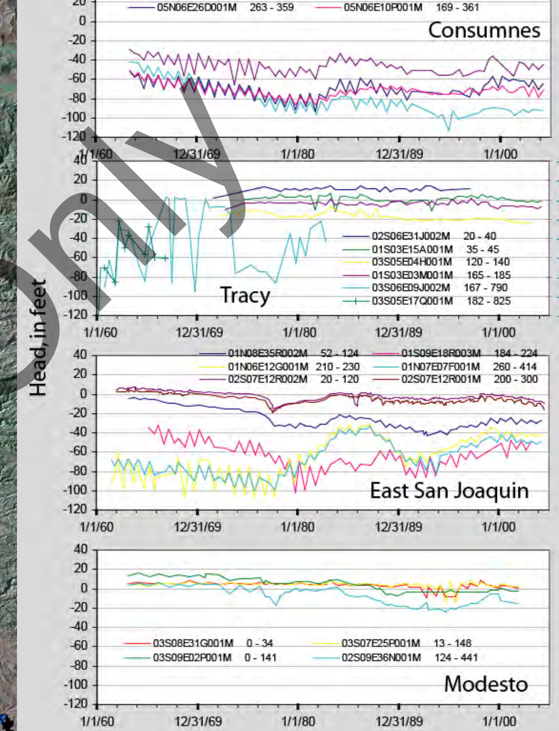
Selection of wells

Continuous record through time frame

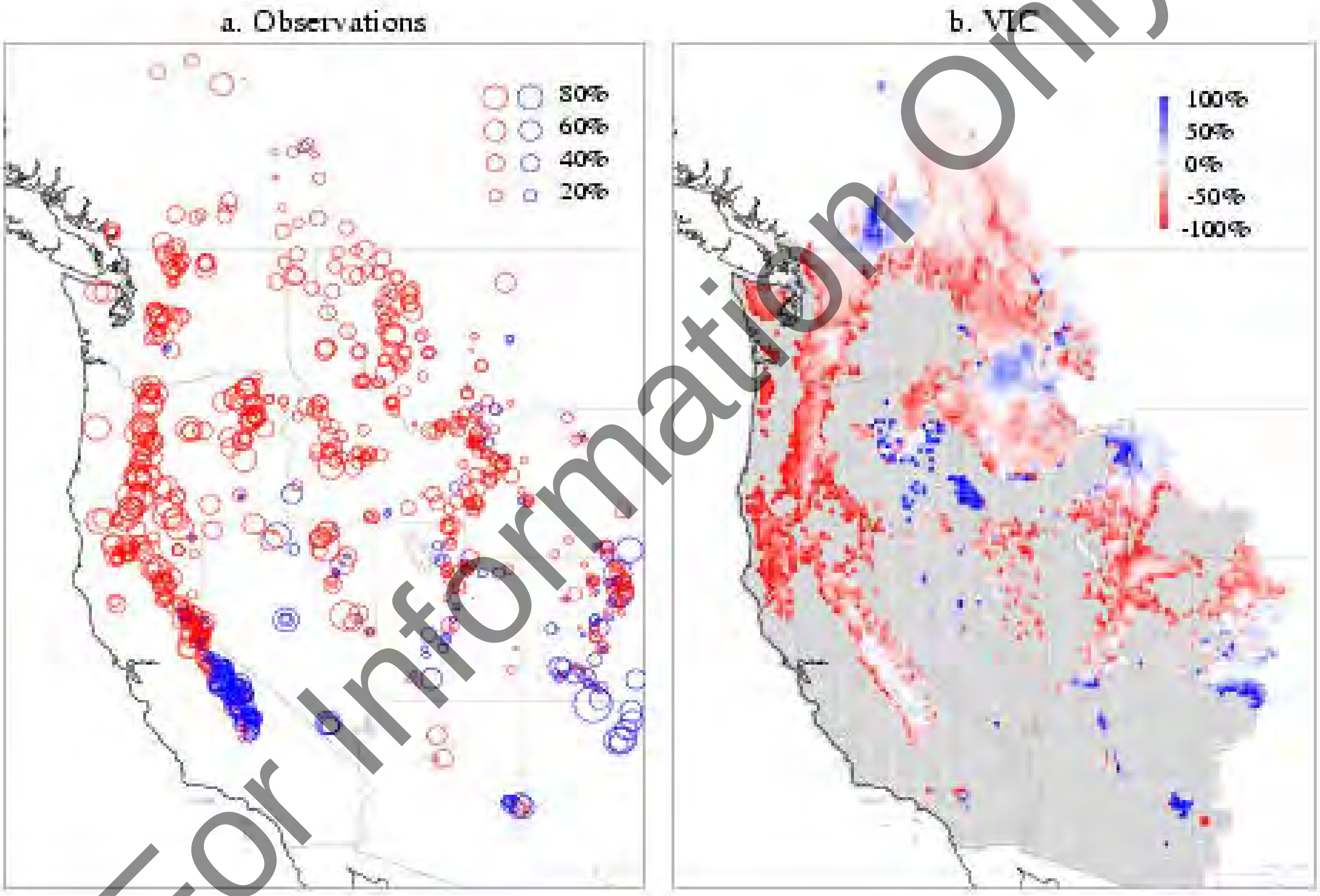
170 wells selected representative of

- 1960 – 2003
- Subareas



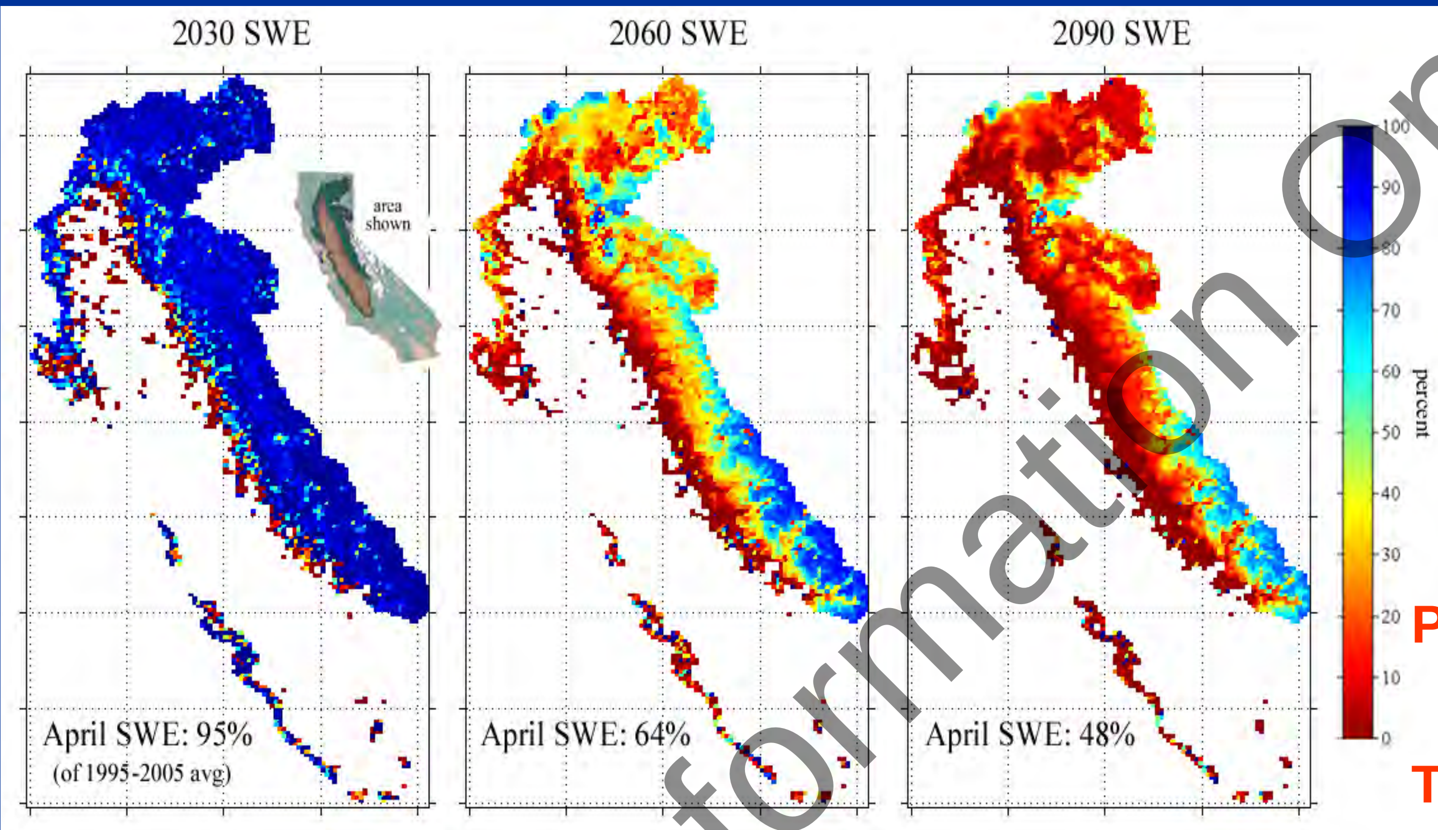


Downward Trends in April 1 Snow Water Equivalent 1950-1997



Source: Mote et al. (2004)

We face significant losses of spring snowpack



- Less snow, more rain
- Particularly at lower elevations
- Earlier run-off
- More floods
- Less stored water

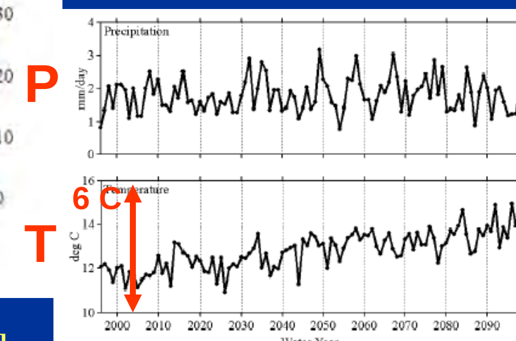


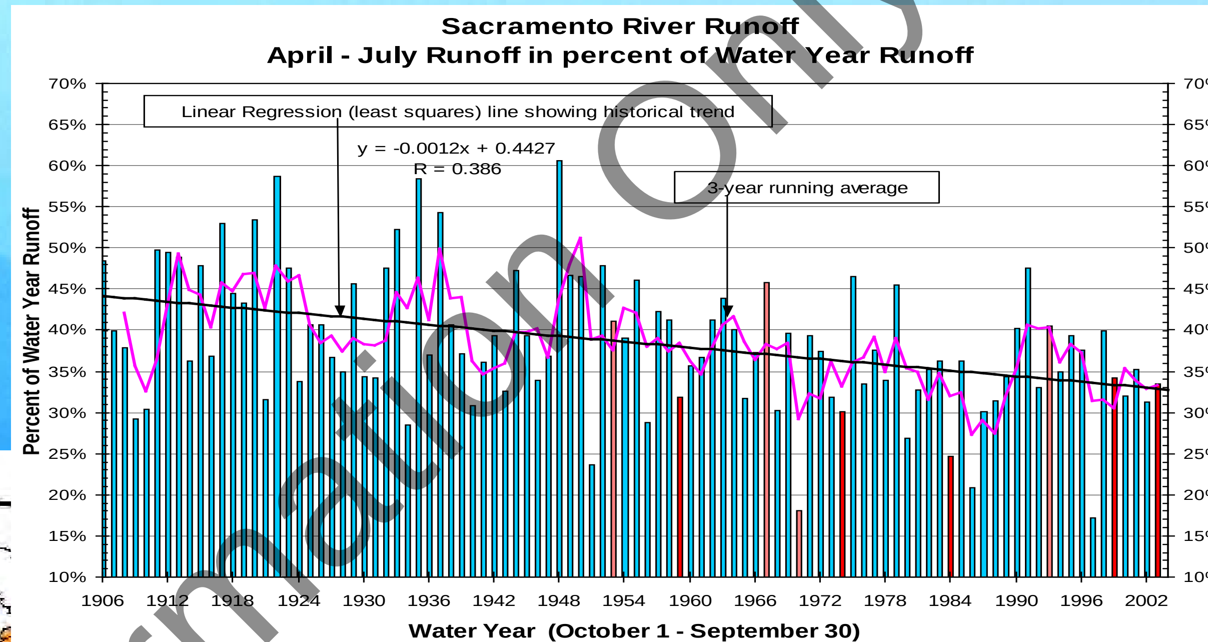
Figure 2. PCM-simulated watershed-averaged annual precipitation and temperature for WY 1995-2099.

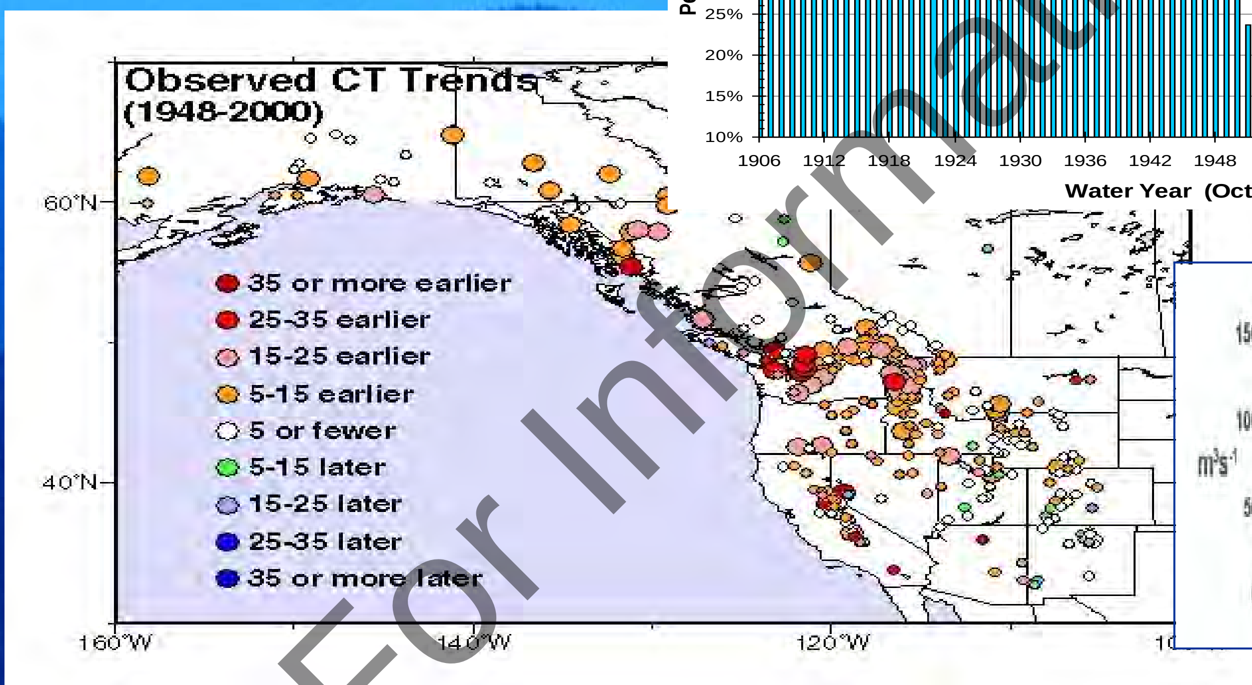
By the end of the century California could lose half of its late spring snow pack due to climate warming. This simulation by Noah Knowles is guided by temperature changes from PCM's Business-as-usual coupled climate simulation. (a middle of the road emissions scenario)

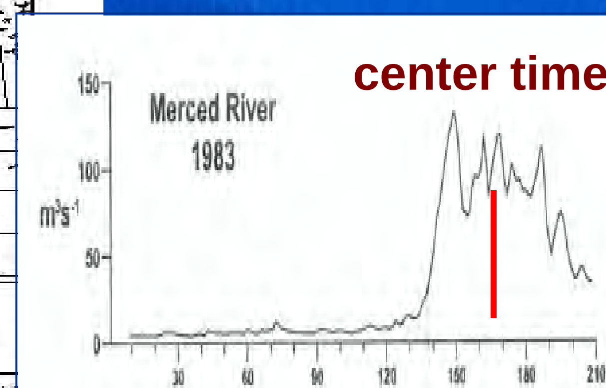
Potential effects of global warming on the Sacramento / San Joaquin watershed and the San Francisco estuary

Noah Knowles and Dan Cayan, Climate Research Division, Scripps Institution of Oceanography/USGS

Earlier spring flows last 2-3 decades







"Center Timing" of snowmelt watersheds have advanced by 1-5 weeks earlier across West

(Stewart et al., 2004)

Today's Presentation

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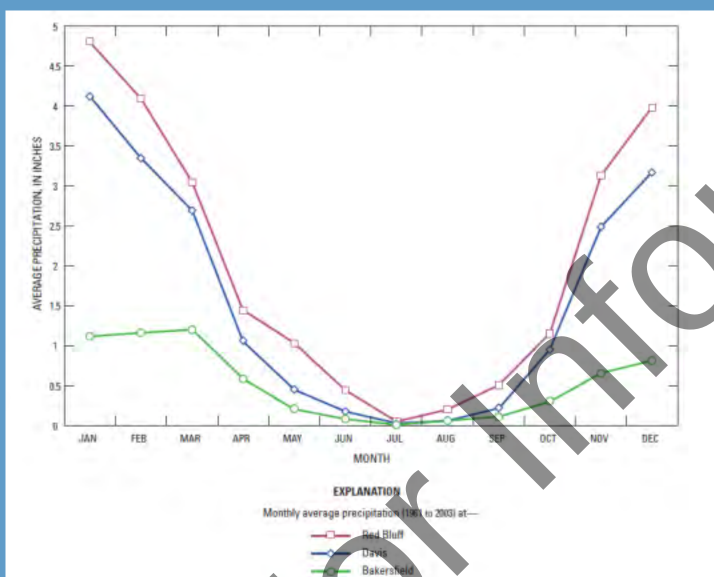
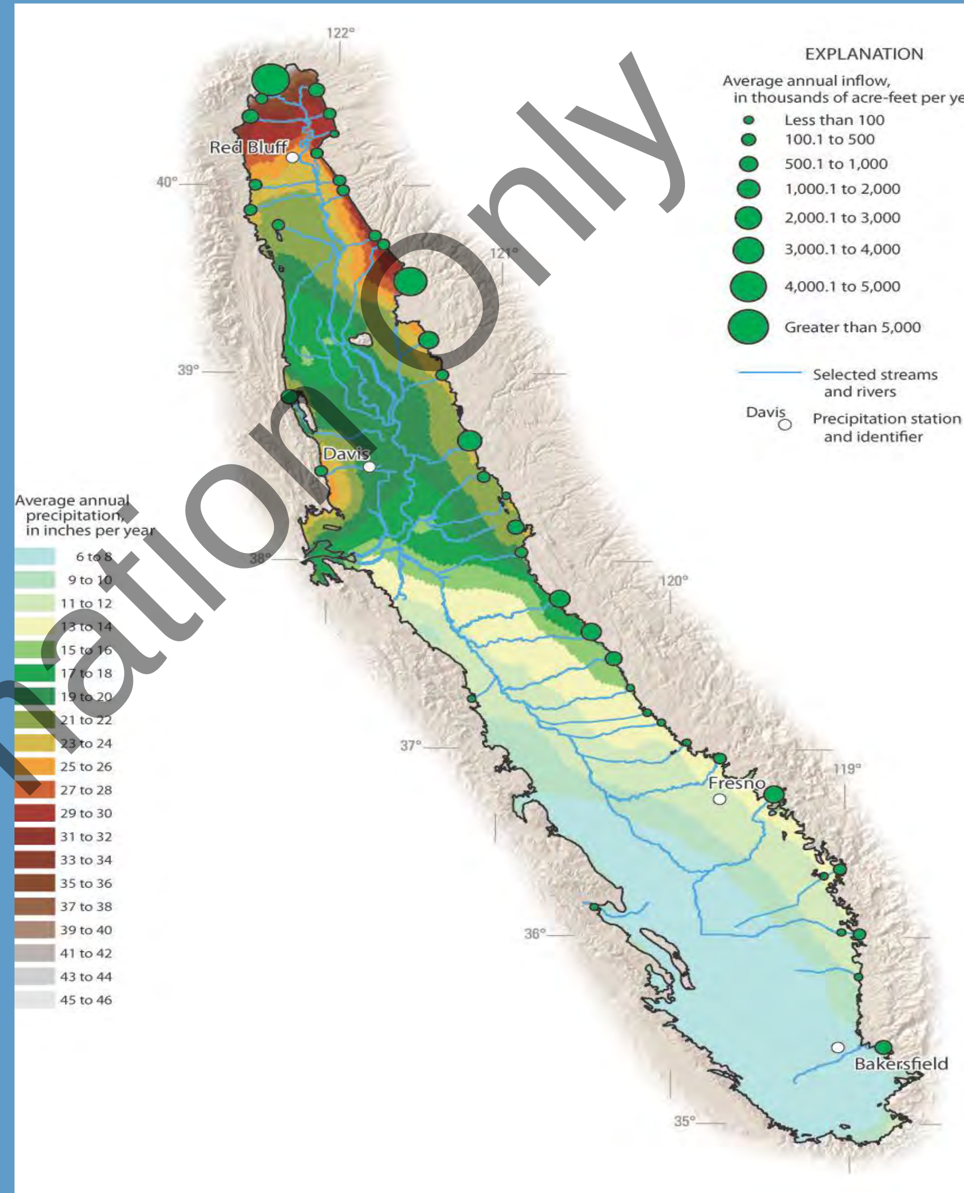
Scripts/Tools

Climate Analysis

Climate: Precipitation

- Vary Geographically
- Vary with Time
  - Annually
  - Seasonally





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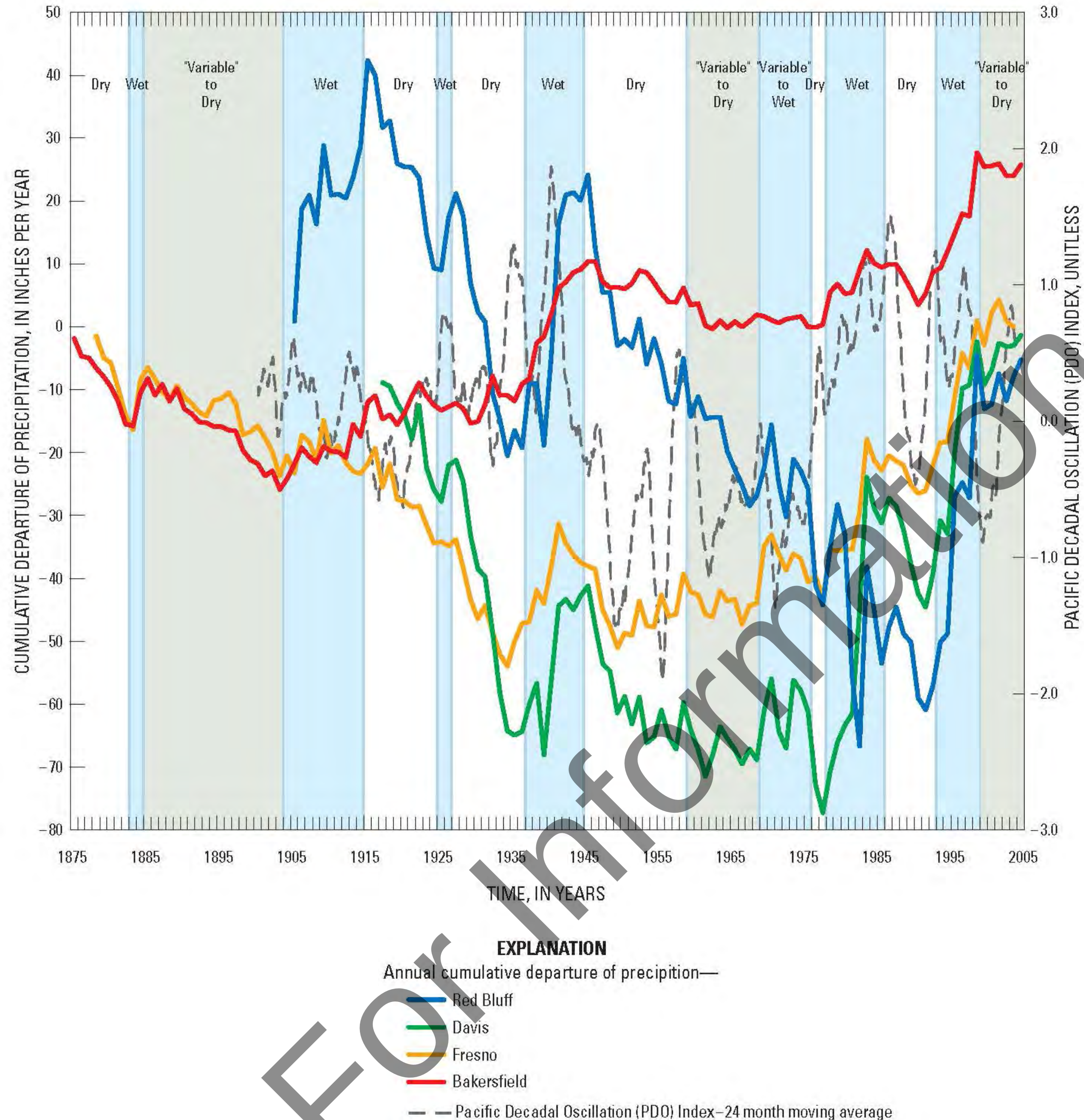


Figure A17. Cumulative departure from average annual precipitation at Redding, Davis, Fresno, and Bakersfield, California. For reference, a 24-month moving average of the Pacific Decadal Oscillation Index is also plotted.

All Precipitation does not vary together across the Valley→ Fresno/Bakersfield vs Red Bluff/Davis

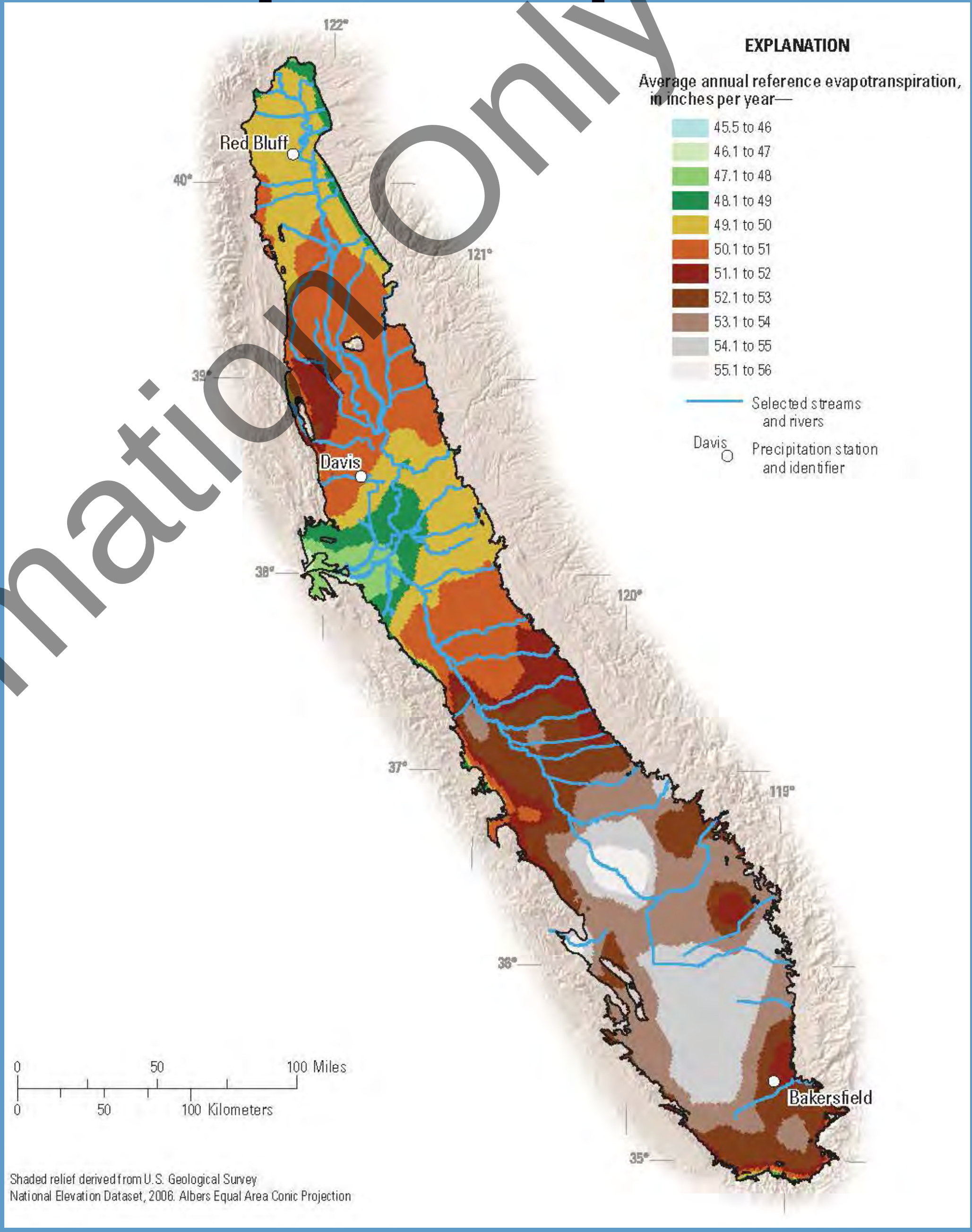
Or in phase with PDO

Today's Presentation

- Climate Background
- Precipitation
- Evapotranspiration
- Scripts/Tools
- Climate Analysis

USGS

Climate: Potential Evapotranspiration



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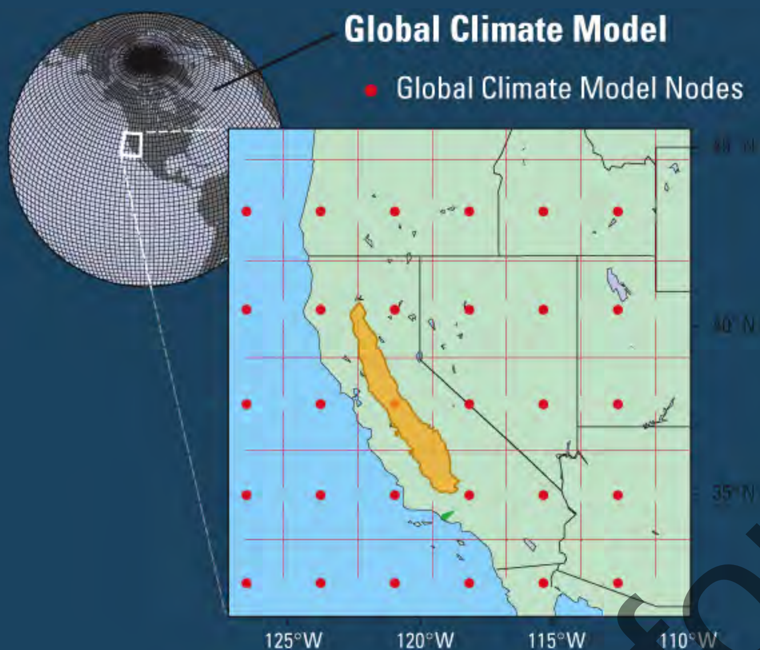


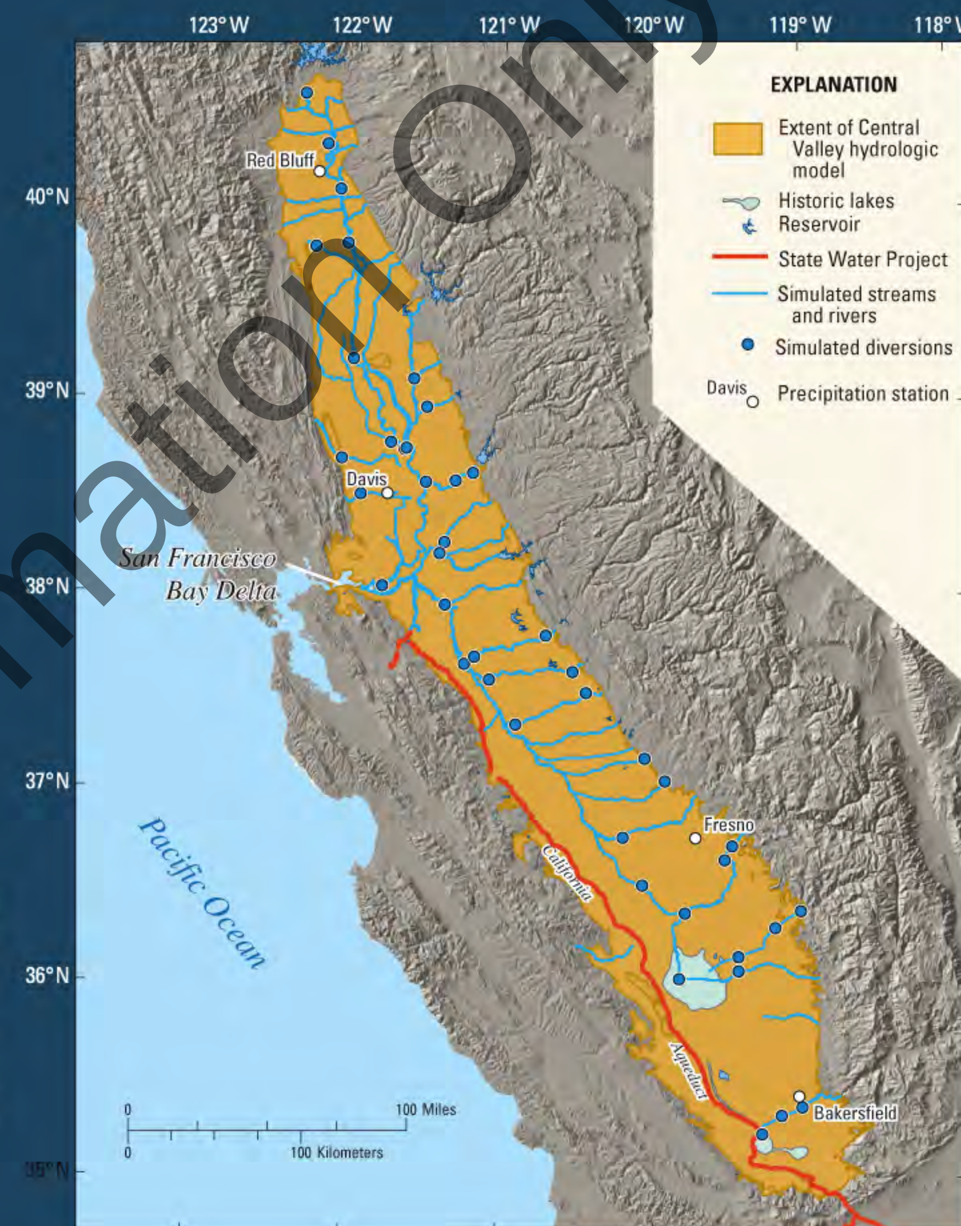


Figure 1. Map of Central Valley Hydrologic Model illustrating relation to the rivers, diversions, and San Francisco Bay Delta

Modified from Hanson and Dettinger, 2005; Faunt and others, 2008a (in review).

Our approach towards downscaling climate change:

- Downscale weather day by day

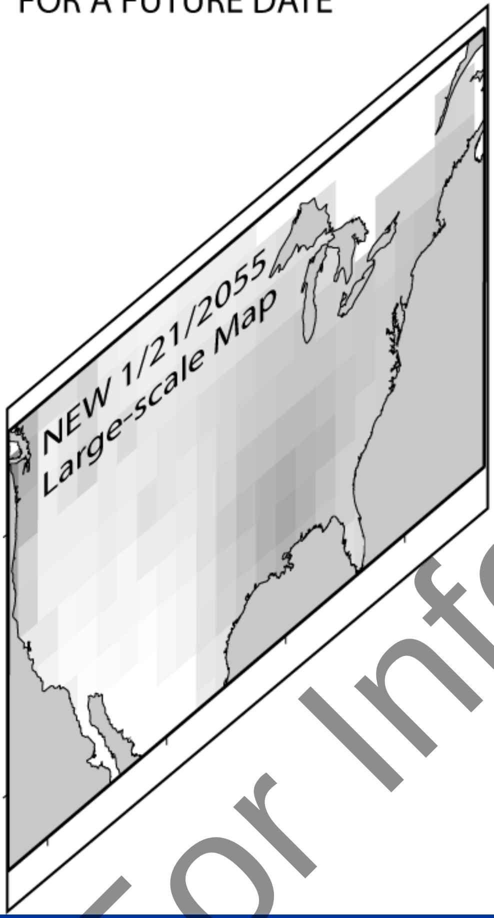
- Downscale enough (daily) weather and you get downscaled climate

- Downscale enough climate and you get downscaled climate change

Don't impose climate or climate change after the fact !

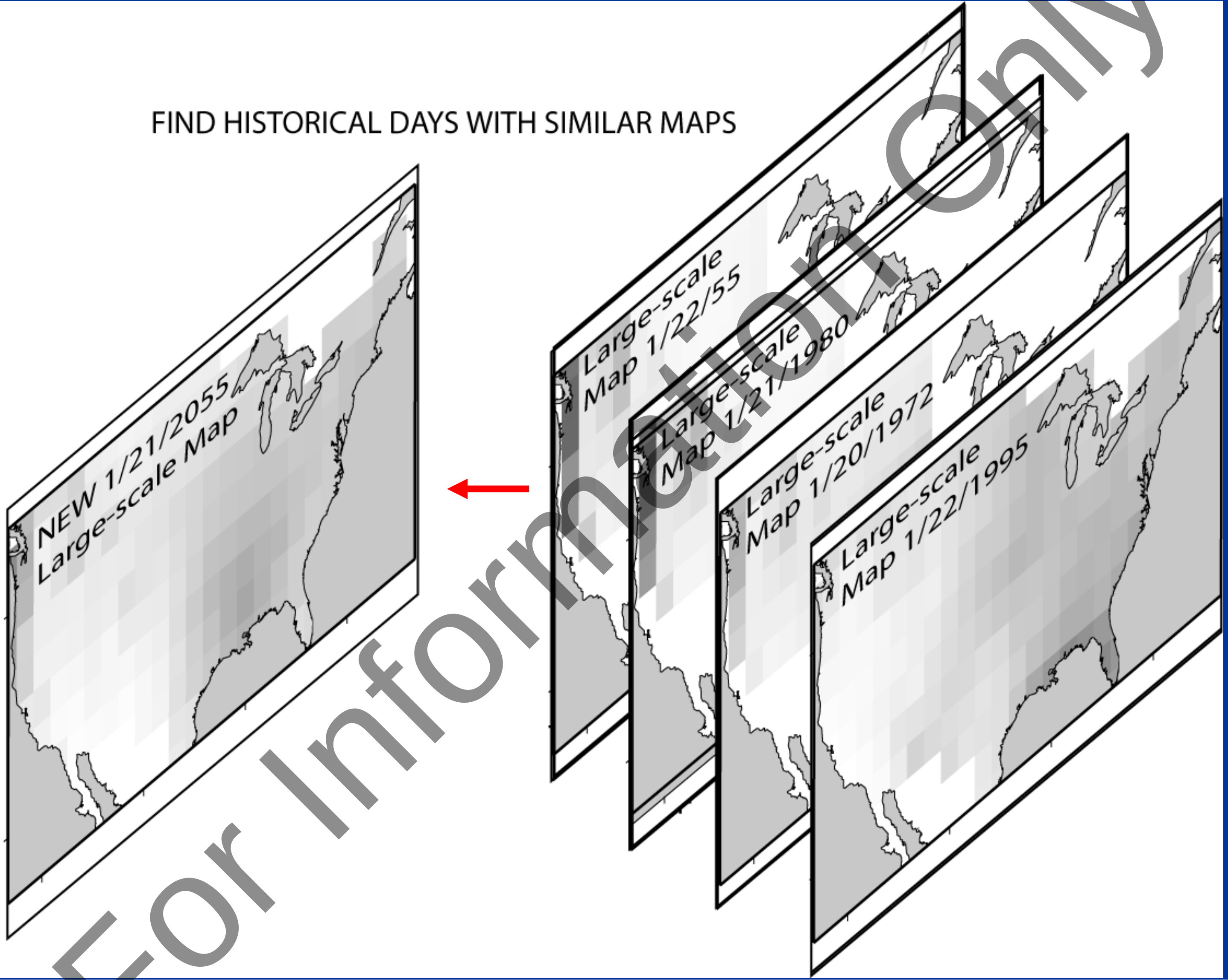
The constructed-analogs method

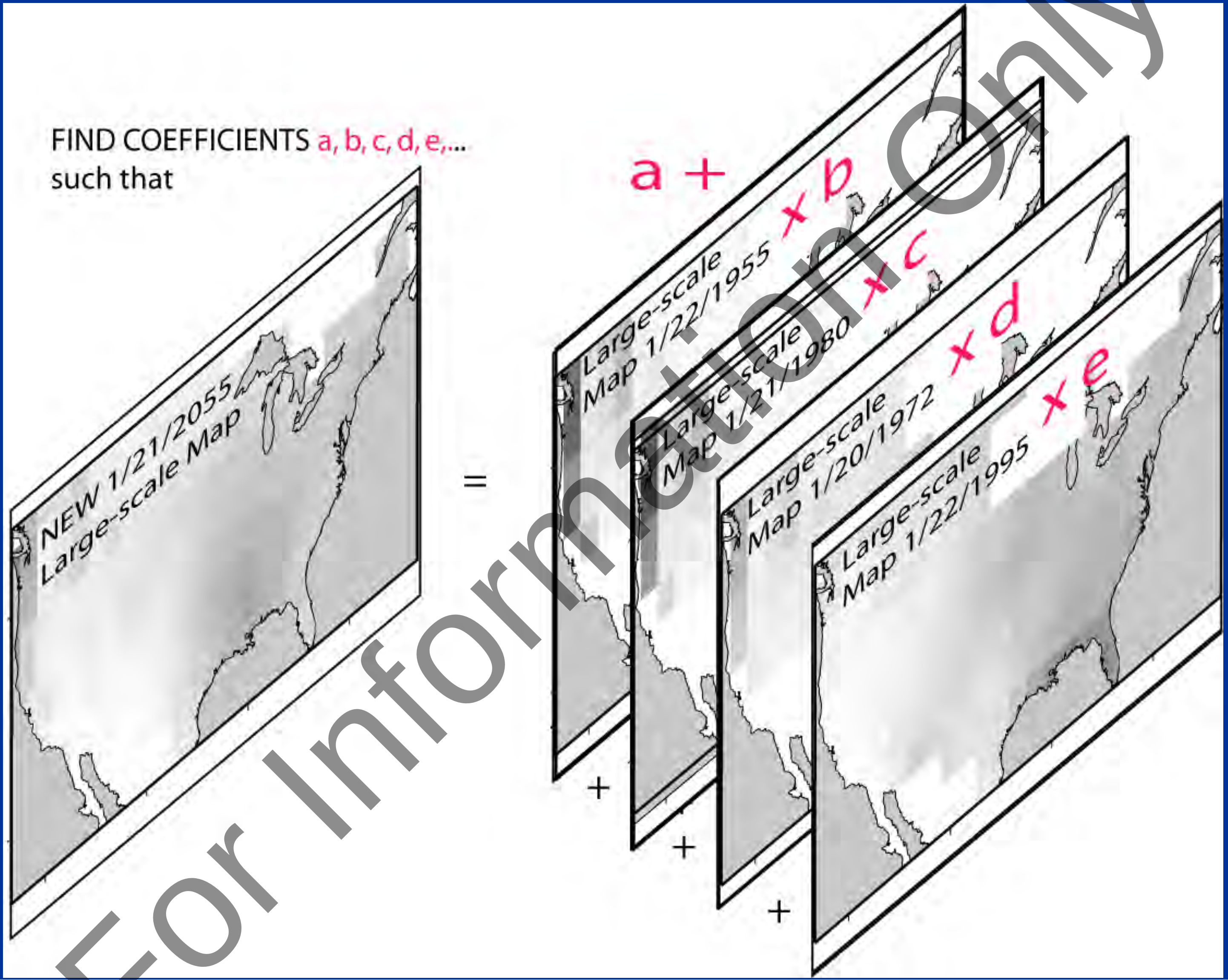
GIVEN THE COARSE RESOLUTION CLIMATE FIELD
FOR A FUTURE DATE

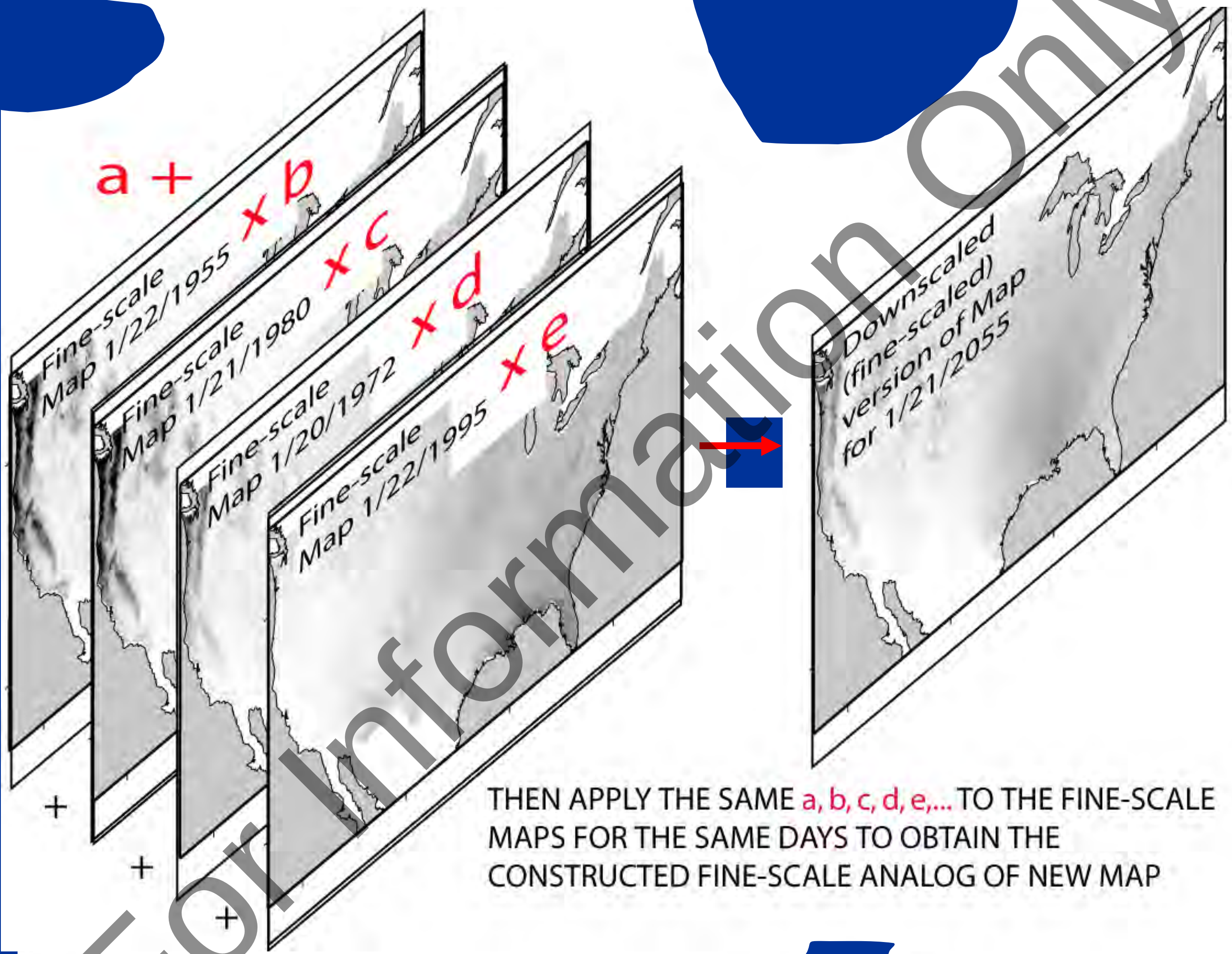


Hidalgo, H.G., Dettinger, M.D., and Cayan, D.R., in review, Downscaling using constructed analogues daily US precipitation and temperatures: J. Climate, 24 p.

FIND HISTORICAL DAYS WITH SIMILAR MAPS

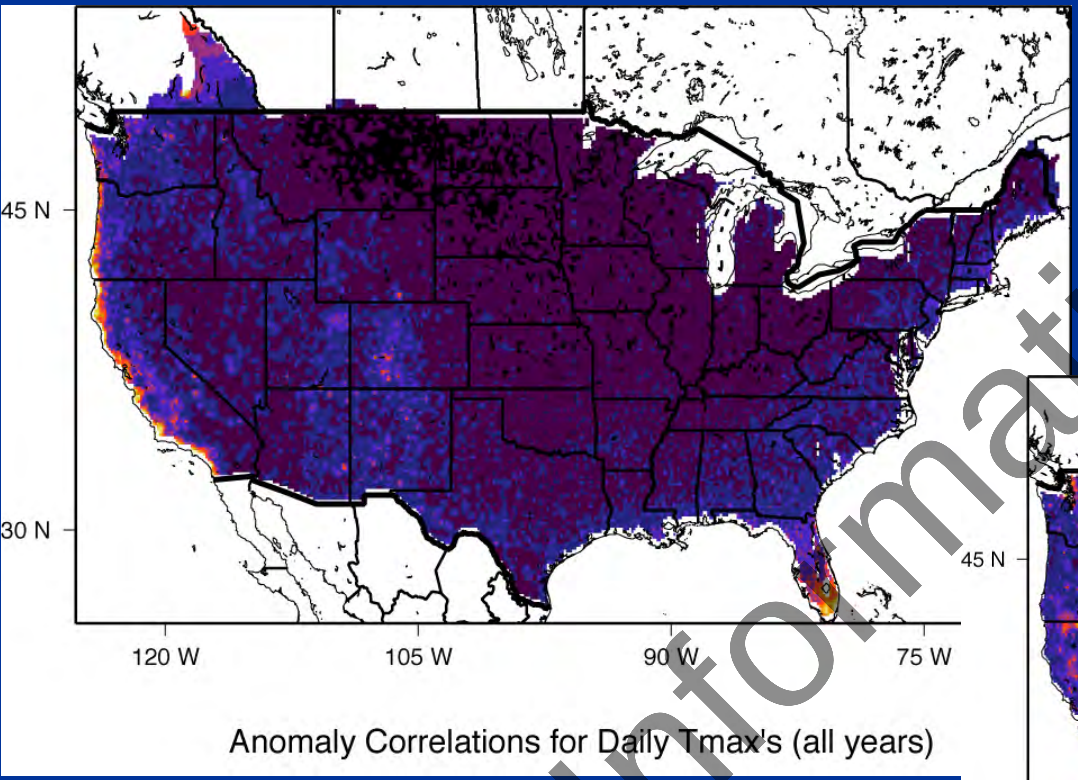


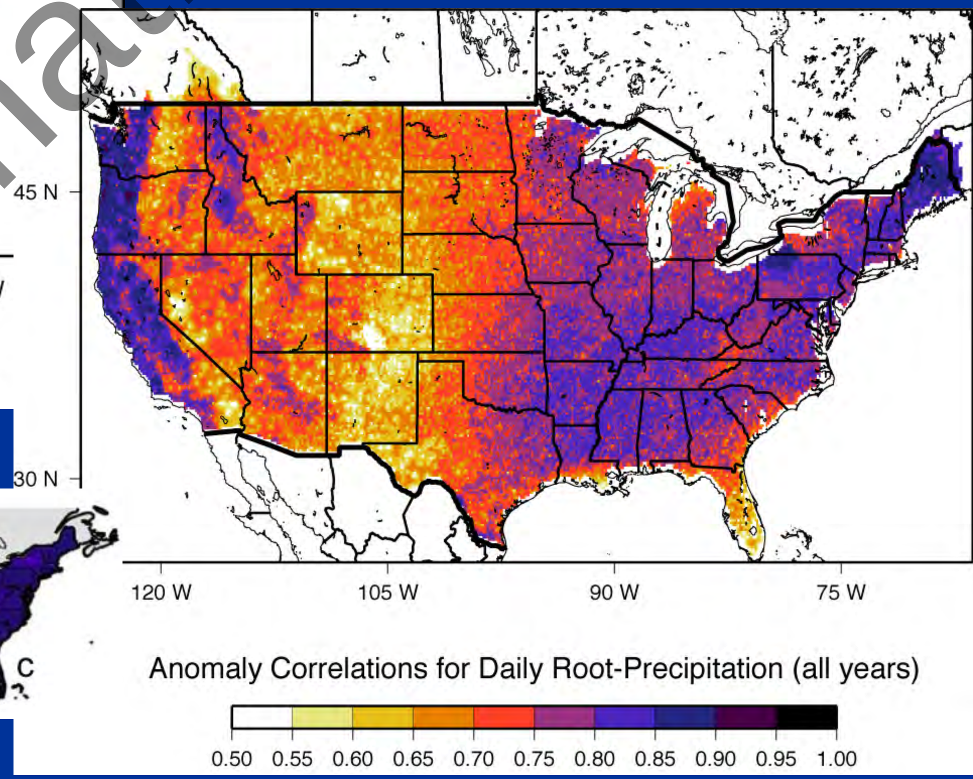

FIND COEFFICIENTS a, b, c, d, e,...
such that
NEW 1/21/2055
Large-scale Map
=
a +
Large-scale
Map 1/22/1955
x b
+
Large-scale
Map 1/21/1980
x c
+
Large-scale
Map 1/20/1972
x d
+
Large-scale
Map 1/22/1995
x e



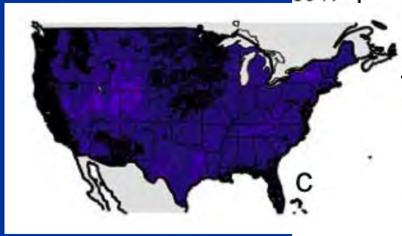
THEN APPLY THE SAME a, b, c, d, e,... TO THE FINE-SCALE MAPS FOR THE SAME DAYS TO OBTAIN THE CONSTRUCTED FINE-SCALE ANALOG OF NEW MAP

Skill of downscaling as indicated by application of method to historical OBSERVATIONS

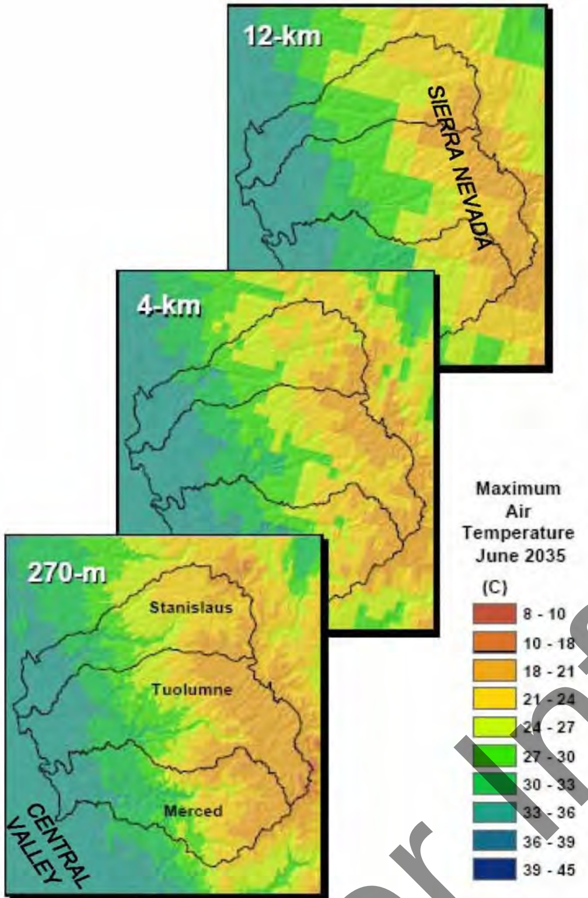




Skill at monthly average scale



Final Downscaling and Bias Correction



Processing sequence:

(1) 2 degree monthly GCM output → 12-km grids using constructed analogues.

(2) 12-km monthly grids (1950-2000 and 2000-2100) → 4-km grids using GIDS.

(3) Bias-correction coefficients are determined using monthly downscaled GCM 4-km grids and historical PRISM data for 1950-2000.

(4) Bias corrections are made on monthly grids using the coefficients. Ratios of corrected to uncorrected data are calculated.

(5) Monthly 4-km bias-corrected grids → 270-m grids using GIDS.

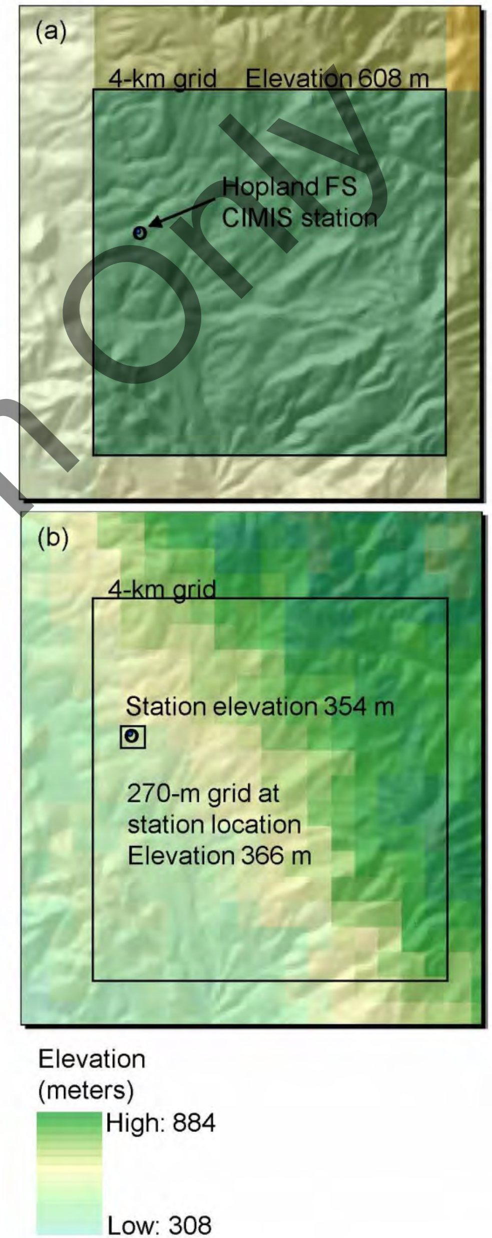


Fig. 2 Close up example of the HOPLAND FS station location within the (a) PRISM 4-km grid cell and the (b) 270-m downscaled grid cell, illustrating their corresponding elevations.

USGS

Flint, L. E., and A. L. Flint, 2012, Downscaling future climate scenarios to fine scales for hydrologic and ecologic modeling and analysis, Ecol. Proc.

CLIMATE DATA → LINKAGE TO INTEGRATED HYDROLOGIC MODELS

PRISM (Climate Source) or Remotely Sensed Data

Precipitation, Temperature, & Ref-ET (Constructed Analogs Method)
4Km/2Km PRISM
1Km TOPS (Ames/NASA)
270m Resampled GIDS (USGS)
MODIS 250m – 1km

Maximum and Minimum Temperature used to estimate Reference ET
Hargrave-Semani Monthly Est.

$$ETh = 0.0023Ra\left(\frac{T_{max}+T_{min}}{2\times 17.8}\right)\left(\frac{T_{max}-T_{min}}{2}\right)$$

where,

T_{max} is the maximum daily air temperature [°C],
T_{min} is the minimum daily air temperature [°C], and
Ra is the extraterrestrial solar radiation (megaJoule/m^2/day).

Farm Process (FMP) Input of Monthly Precipitation & Reference ET
Arc Bilinear Interpolation-Resampling onto Valley-Wide (CVHM) MODFLOW-FMP Grid→Simulate Agricultural Supply & Demand

Maximum and Minimum Temperature used to estimate Reference ET
Presley-Taylor Monthly Est.

$$ET_p = \frac{S}{(S+\gamma)}(Rn - G)\lambda$$

where S = slope of the vapor deficit curve,
= the psychrometric constant,
Rn = net radiation,
G = soil heat flux, and
λ = the heat of vaporization.
The component is a temperature dependent function of the form
SSG = = -13.281 + .083864 * (T_a) - .00012375 * (T_a)^2
where T_a = average monthly air temperature in degrees Kelvin.

Run Central Valley Hydrologic Model (CVHM) (MODFLOW-FMP)

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Decision Support System (DSS) & LINKAGE BETWEEN GCM and BCM & CVHM → Supply-Constrained/Demand-Based Hydrologic Model System

Run GCM Model (CM2/PCM)

Statistical Downscaling
12km →4km Bias Corrected → 270m
Precipitation,
Temperature, & Ref-ET
(Constructed Analogs Method)

Run Basin Characteristic Model(BCM) of all Central Valley Watersheds
Estimate Mountain Runoff/Recharge to Rivers & Reservoirs

Farm Process (FMP) Input of Monthly Precipitation & Reference ET
ET_p *(future)* = (SSG_f/SSG_c) * ($ET_{p\ current}$)
Resampling onto Valley-Wide (CVHM) MODFLOW-FMP Grid→Simulate Agricultural Supply & Demand

Build Stream Routing/Deliveries
41 River Inflows, 66 Diversions,
42 Nonrouted deliveries
(Reservoir Releases,
Unregulated Streamflows &
Project Water Deliveries)

Run Central Valley Hydrologic Model (CVHM) (MODFLOW-FMP)

DSS →Analyze Flows
Groundwater,
Surface-water, &
Landscape Budgets

DSS → Analyze Levels
Groundwater Levels,
Streamflow,
& Land Subsidence

DSS → Analyze Supply/Demand
Drought Response
& Adaptation

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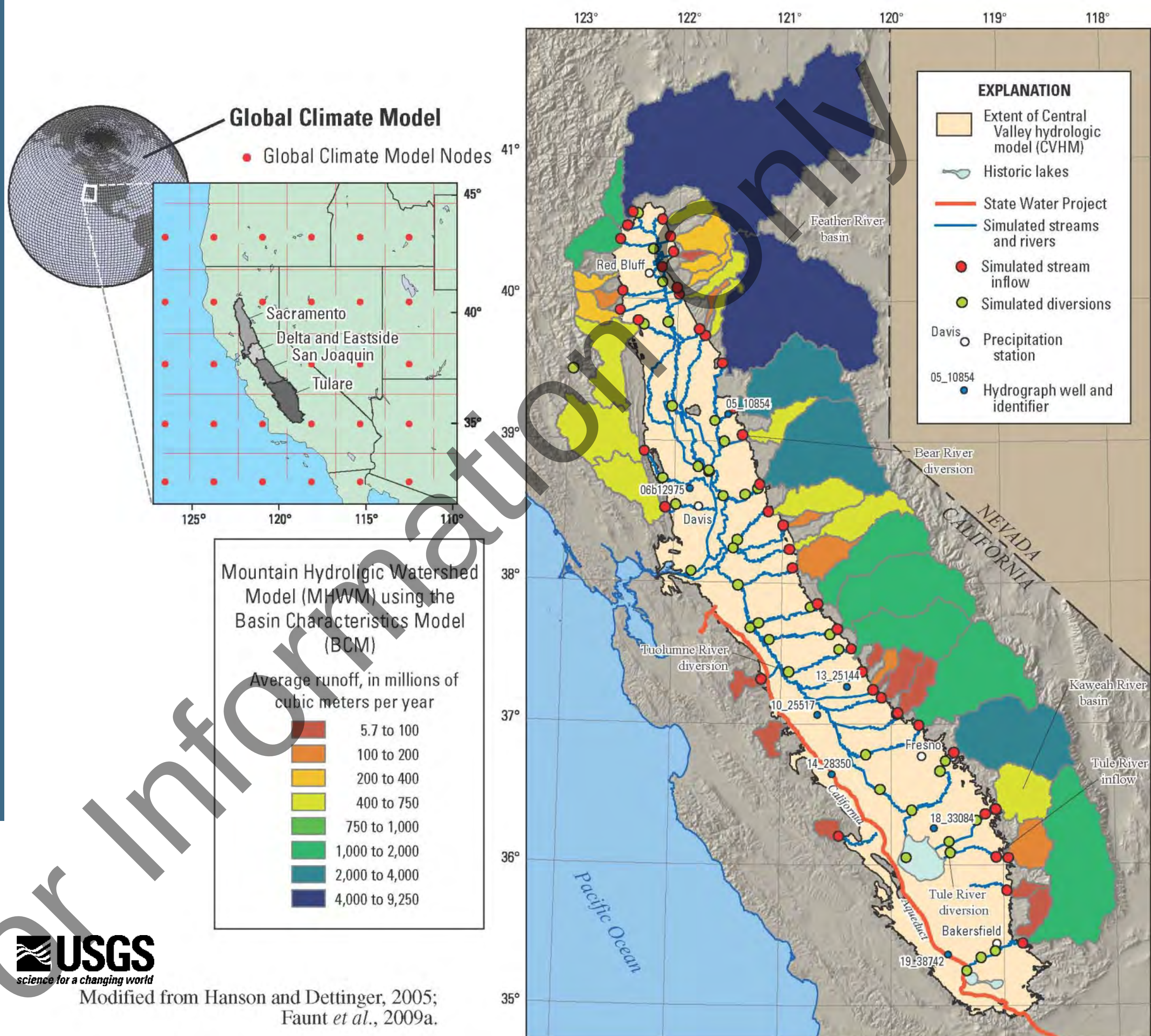
Basin Characteristics Model (BCM) Simulates Precipitation-Runoff/Recharge from downscaled climatology in the mountain watersheds surrounding the Central Valley (Sierra Nevada and Coast Ranges Mountains)

Also Developing Linkage with VIC Model



Modified from Hanson and Dettinger, 2005; Faunt *et al.*, 2009a.

Linkage of Global Climate Model to Regional Hydrologic Models

A2- Scenario & Model Linkages

- **Future projection (A2)** → Extreme conditions - generally characterized as climatically quite, warm, substantially drier, assumes high growth in population, regionally based economic growth, and slow technological changes that represents "heavy emissions" and "business as usual" increase in future greenhouse emissions (Cayan et al., 2009). → Reduced Snowfall, reduced Precipitation, Increased Temperature and ET

- **Model Assumptions**:
  (1) No Adaptation → Land use (Agriculture, Urban, & Native) held constant at 2006.
  (2) Future urban water use → Increase 1.2% per year through at least 2040.
  (3) Sea-Level rise GW only → One meter rise with monthly variation in sea level at Delta controls groundwater outflow.

- **GCM → MHWM (BCM) & CVHM (MF-FMP) used to evaluate potential effects of extreme climate change on conjunctive use of water** → Runoff & recharge from mountains, irrigation supply & demand, and groundwater, surface water, and agricultural components

- **Simulation Response metrics of Conjunctive Use** → SW Diversions, streamflow and infiltration/base-flow, groundwater storage, and related effects → potential land subsidence and groundwater/surface-water relations in the Sacramento Delta.

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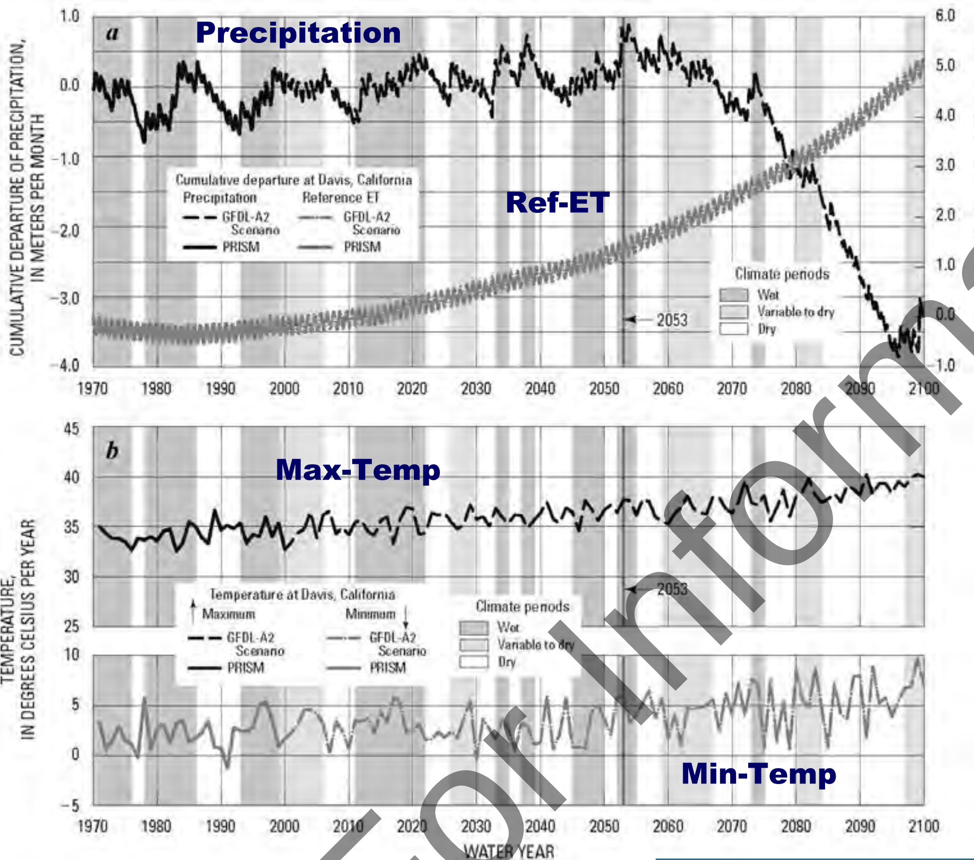
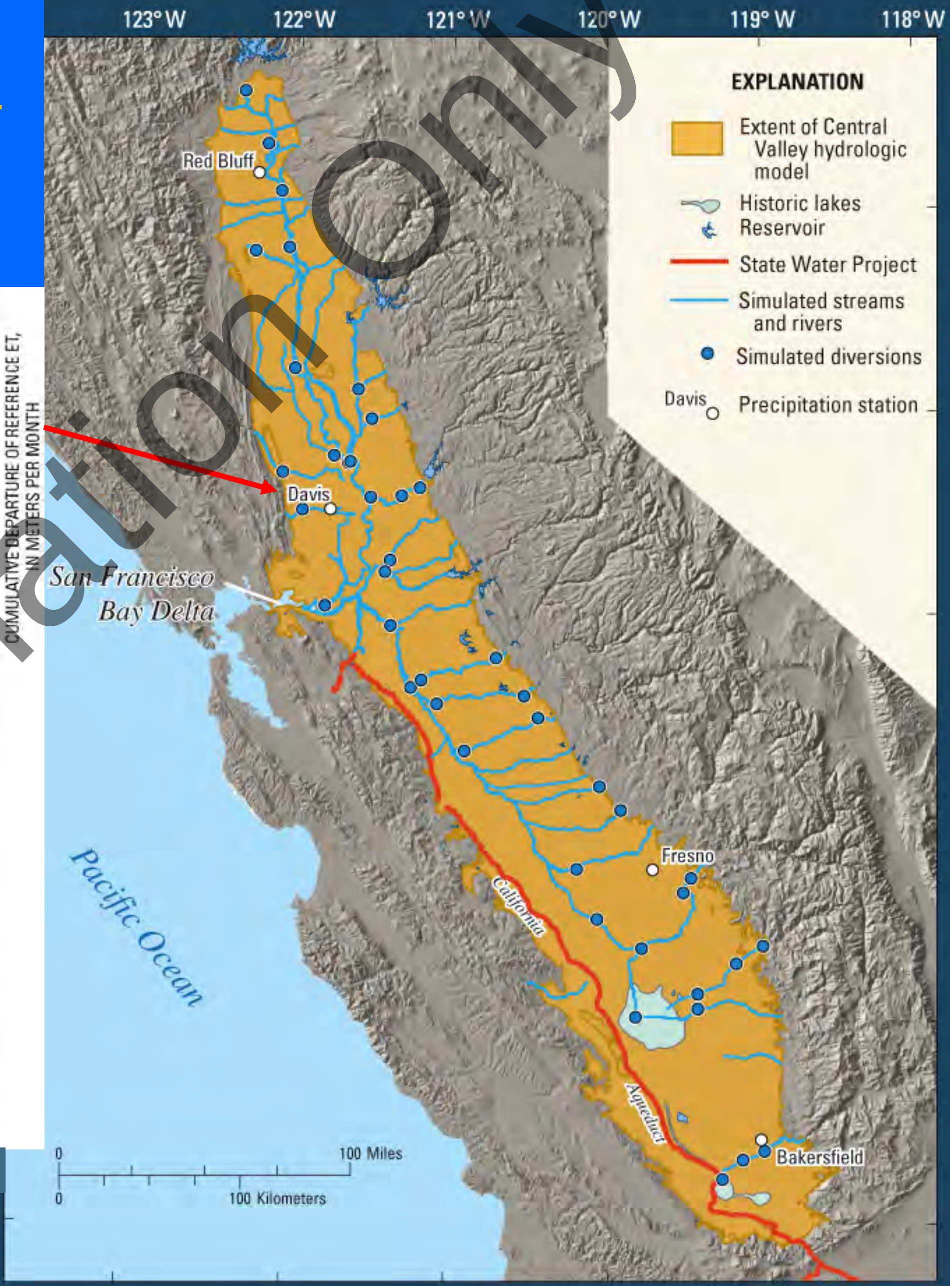
Cumulative Precipitation & Temperature Downscaled

Shows A2 Scenario at Davis with the potential for

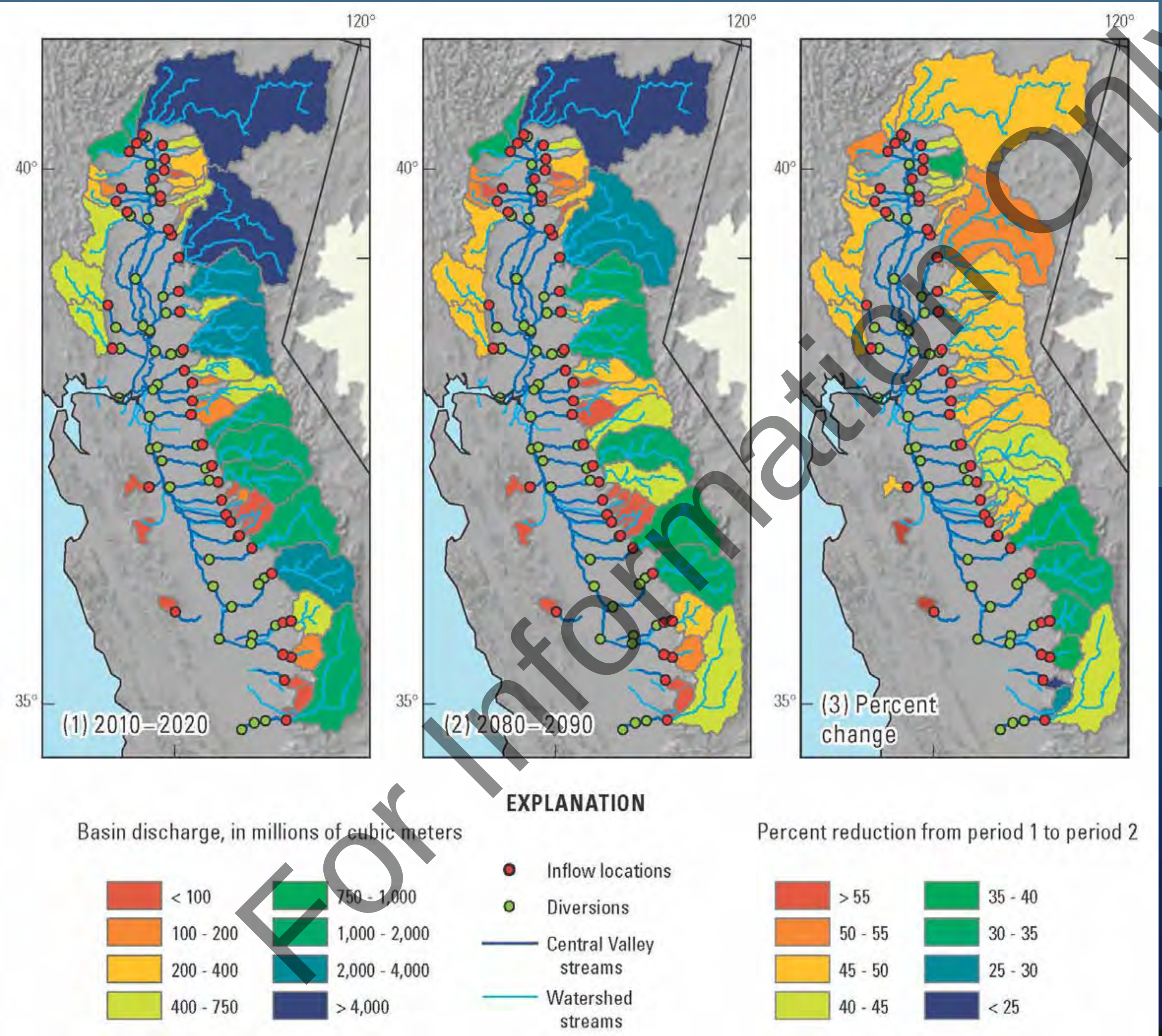
- Decreased Precipitation
- Increases in Temperature of +2 to+4°C & ET
- Sustained droughts in the 21st Century (10-15% Drier)





Faunt and others, 2009 (USGS Prof. Paper 1766)

Discharge Reduced by 20 – 65%→Largest in North & Central



Mean total basin discharge for

(1) 2010-2020,

(2) 2080-2090,

(3) Percent reduction in discharge between the 2 decades, for each of the 43 basins in the study area.

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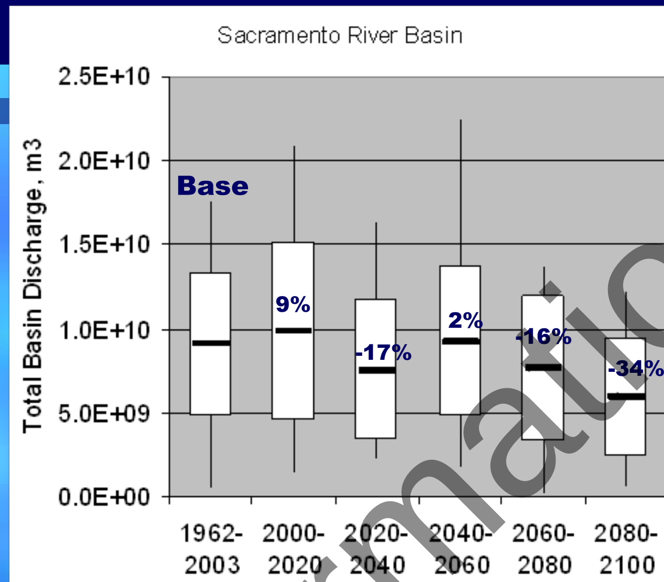
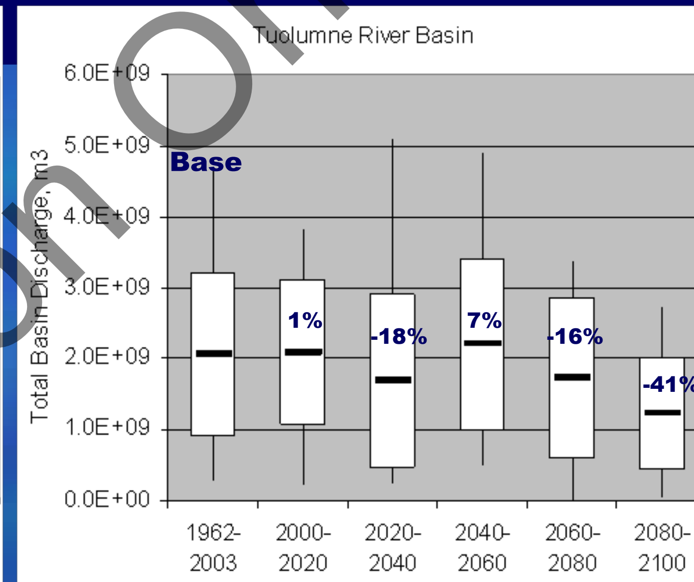
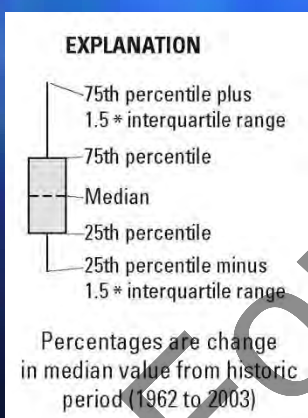
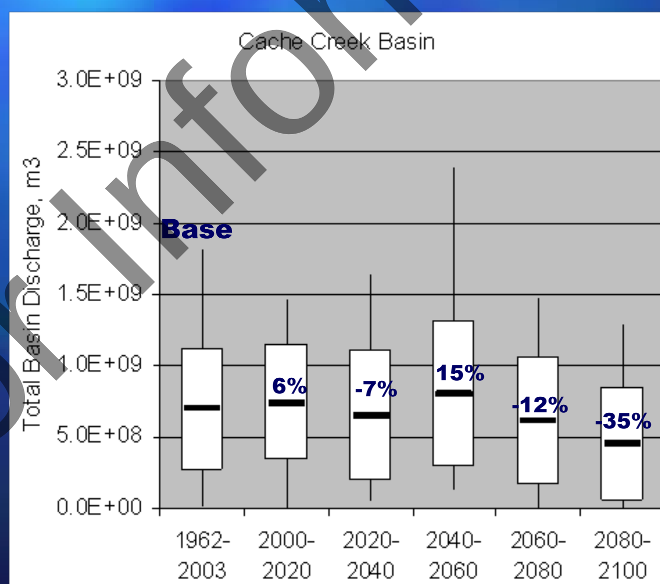
Current (1962-2003) modeled and future 20-year projections of total basin discharge for 4 basins in the study area, depicted as mean (black bar), standard deviation (white box), and range (vertical lines). Percent change in future mean discharge from current mean is indicated for each 20-yr period.

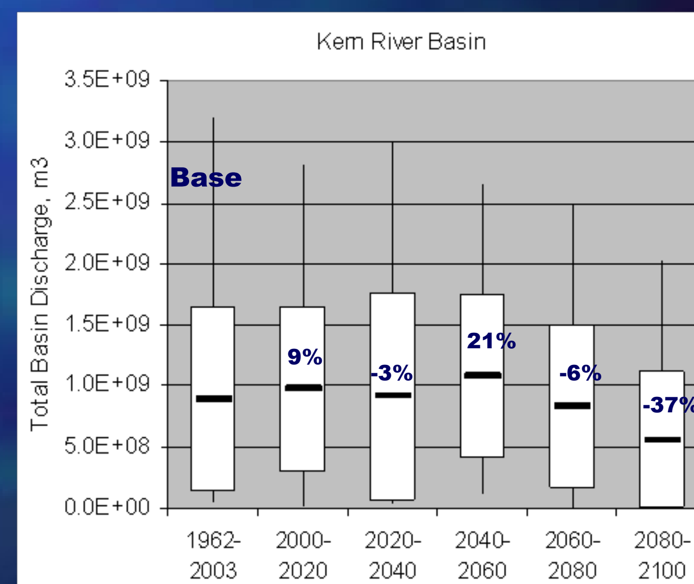




Streamflow Reductions of ~30 – 40% from major Rivers flowing from Sierra's to Central Valley in later decades of 21st Century







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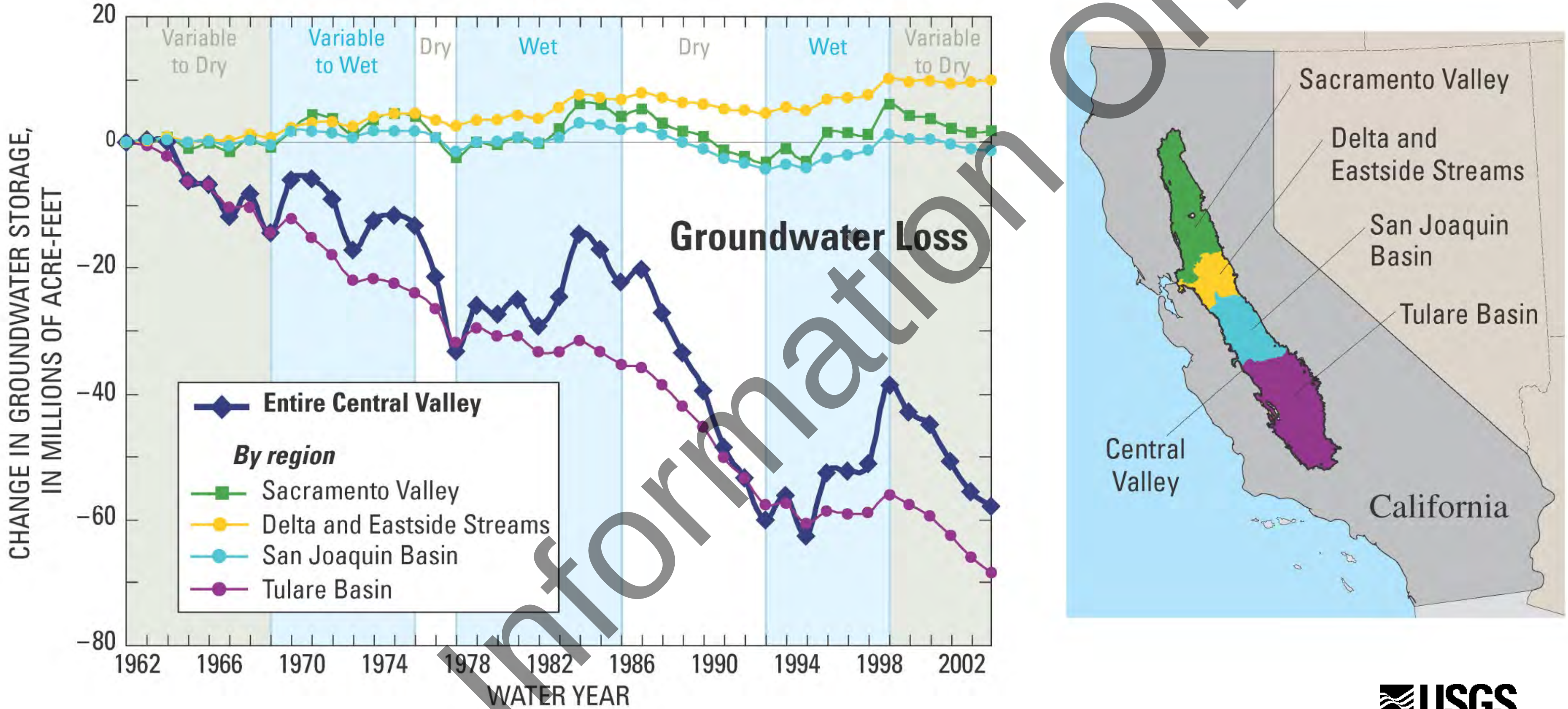
Historical Change in Groundwater Storage (Water Years 1961 – 2003)



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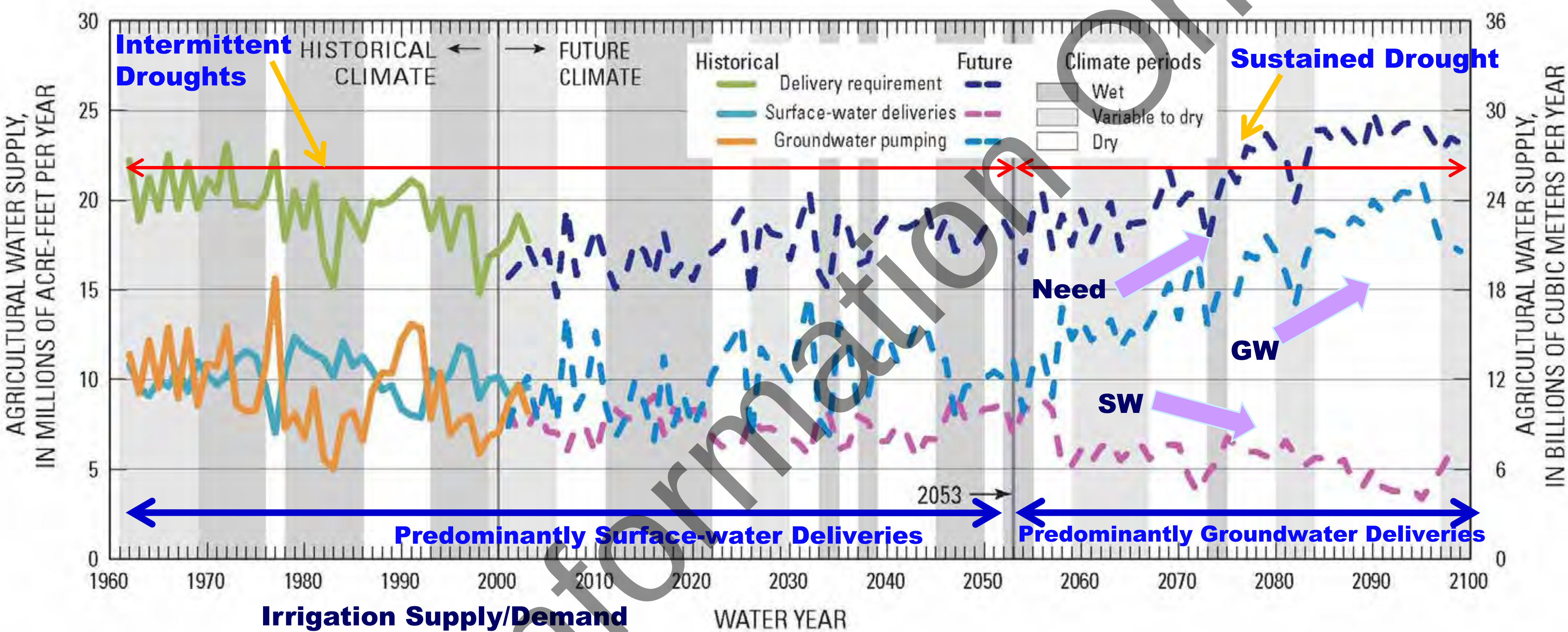
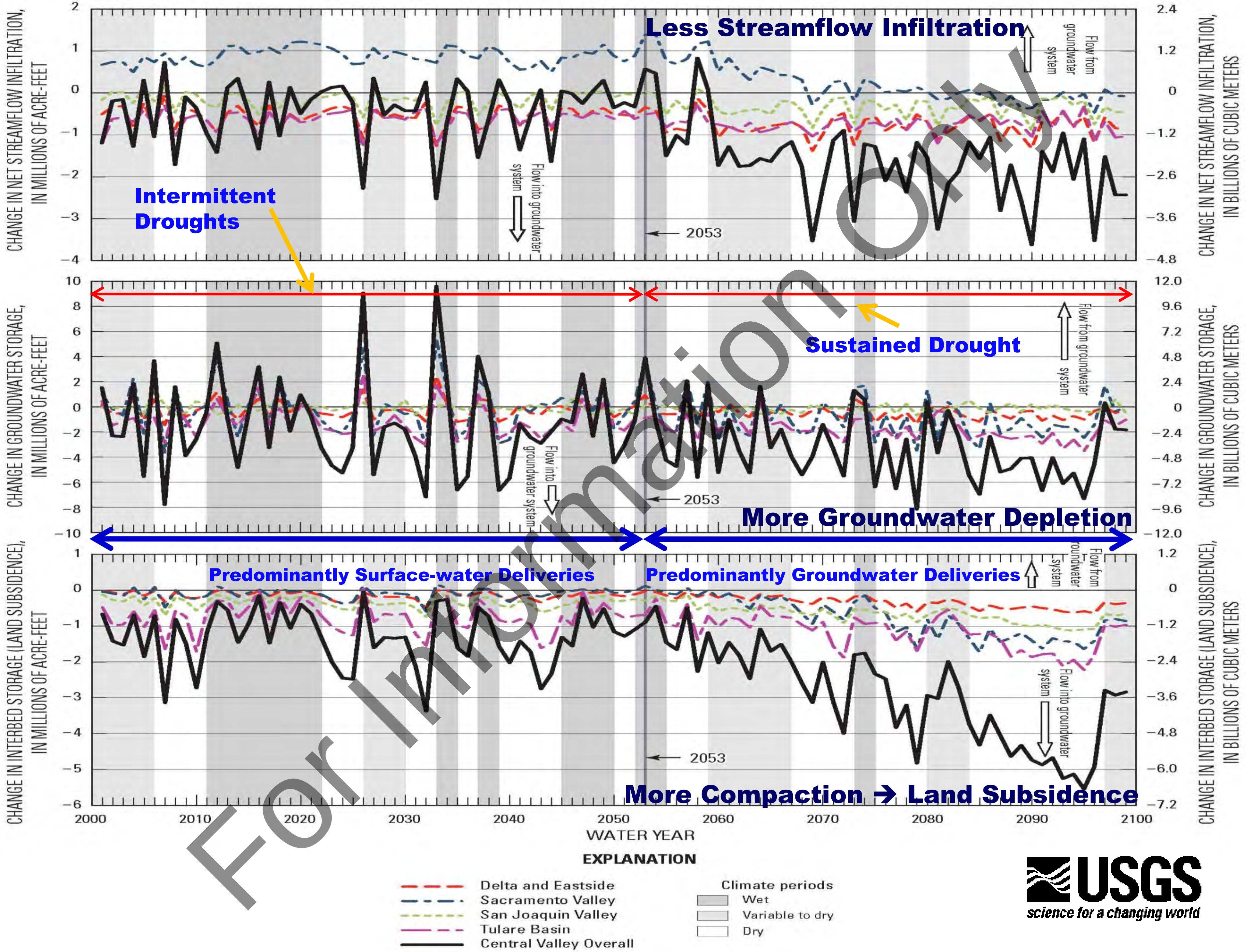
Agricultural and Urban Water Supply → 20% of a groundwater pumped in USA

Faunt, C.C., Hanson, R.T., Belitz, Kenneth, and Rogers, Laurel, 2009, California's Central Valley Groundwater Study: A Powerful New Tool to Assess Water Resources in California's Central Valley: U.S. Geological Survey Fact Sheet 2009-3057, 4 p. (http://pubs.usgs.gov/fs/2009/3057/)

Conjunctive Use Transition from Surface-Water to Groundwater Use



- Historical Surface-water to groundwater deliveries averaged about 1.33-to-1, (ranging from 2-to-1 ➔ wet periods to 1-to-3 during persistent dry periods)
- GFDL-A2 scenario yields modeled ratios of surface-water to groundwater deliveries averaged about 1-to-2.75 (ranging from 1-to-1 ➔ wet periods to 1-to-3 during dry epochs)



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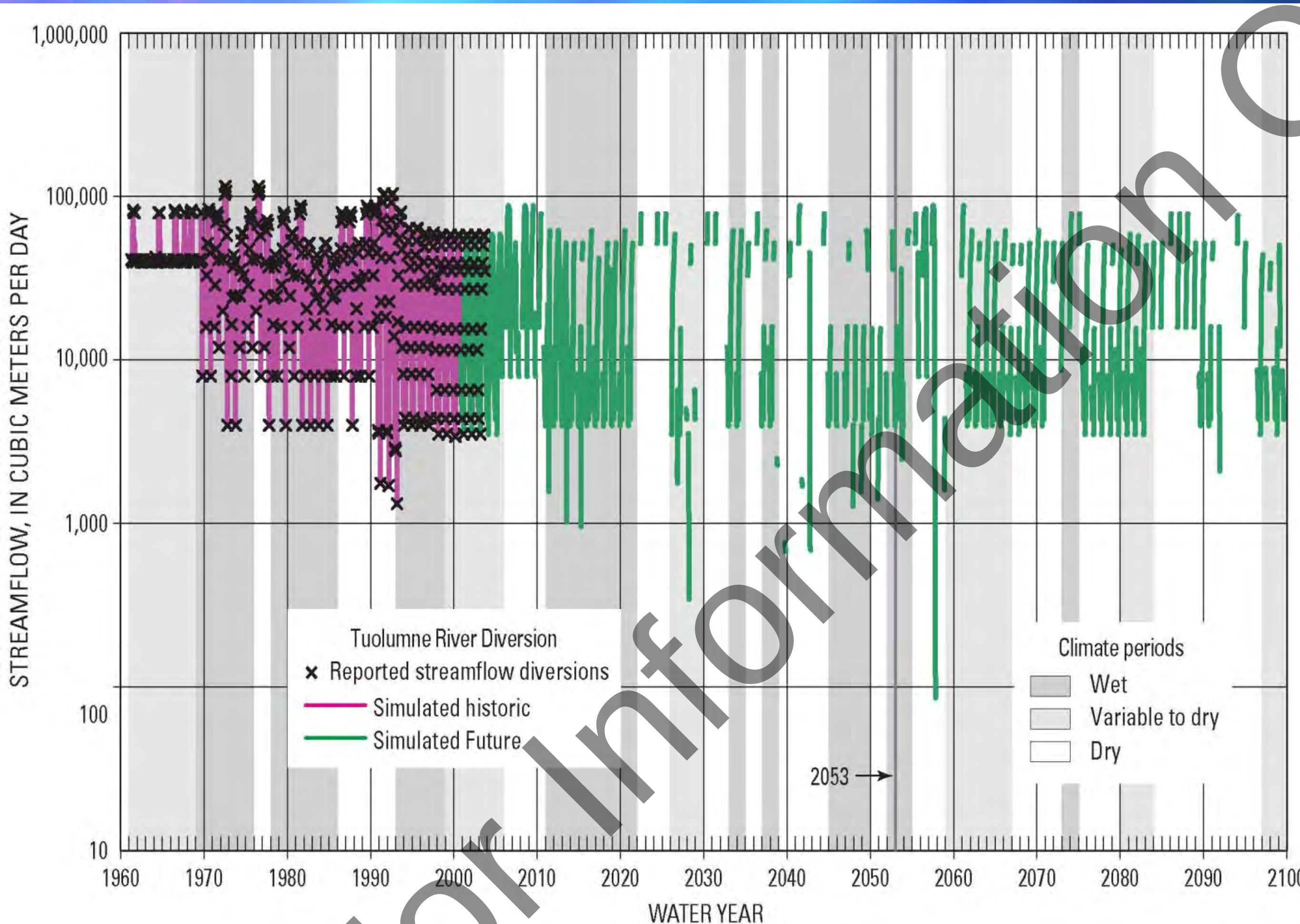
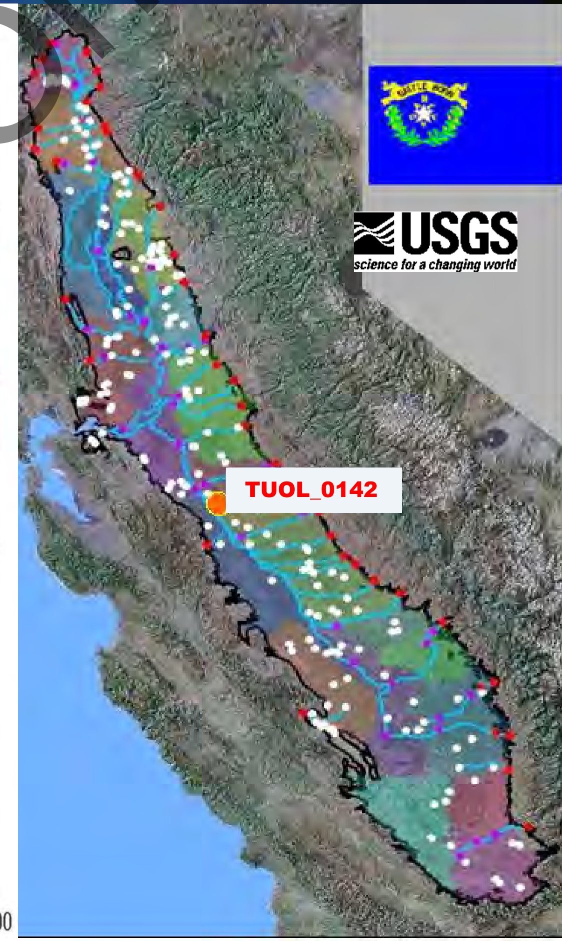
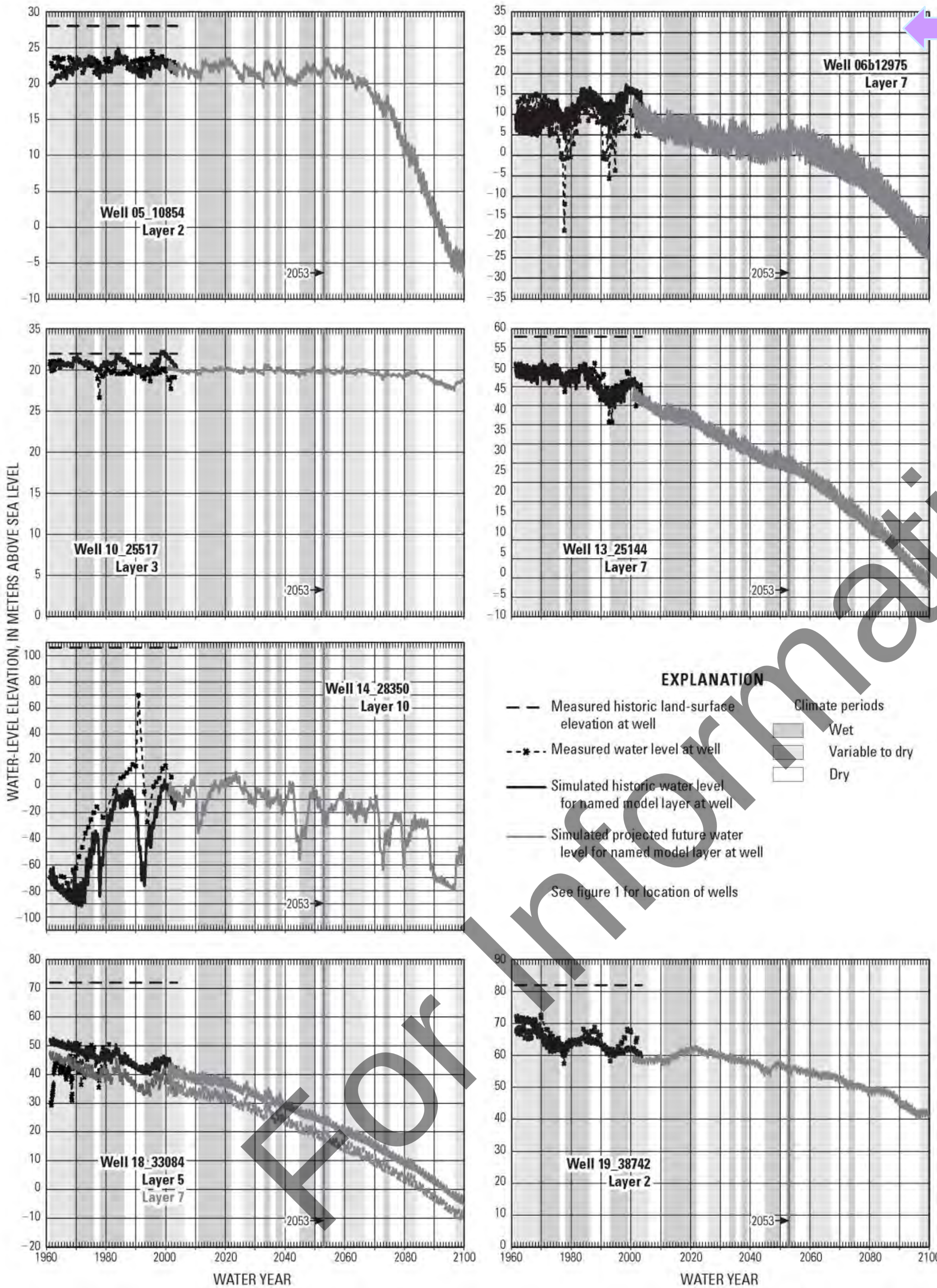
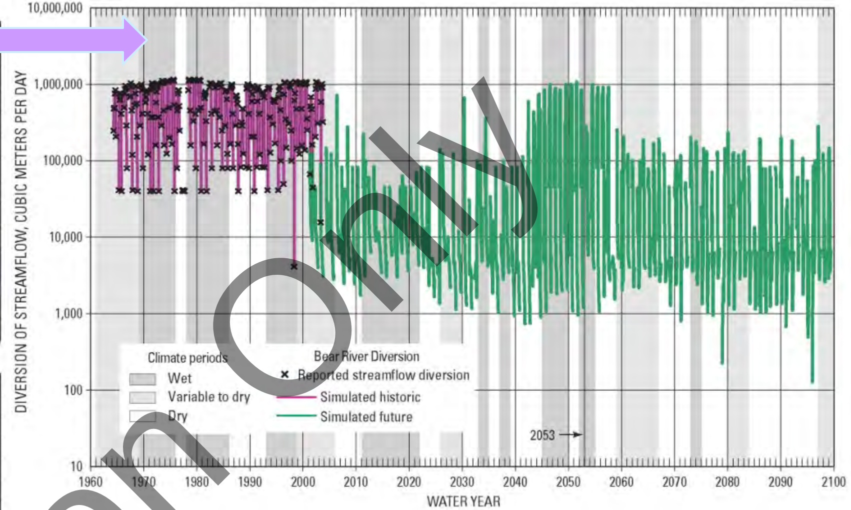
A2-Reduction in Surface-Water Diversions for Riparian Habitat on the Tuolomne River, San Joaquin Valley, Central Valley, California





Water diverted for maintaining Riparian Habitat from the Central Sierras may become intermittently unavailable in 21st Century





Continued Increase in Groundwater Demand → Increased Pumpage → Increased Declines in groundwater Levels

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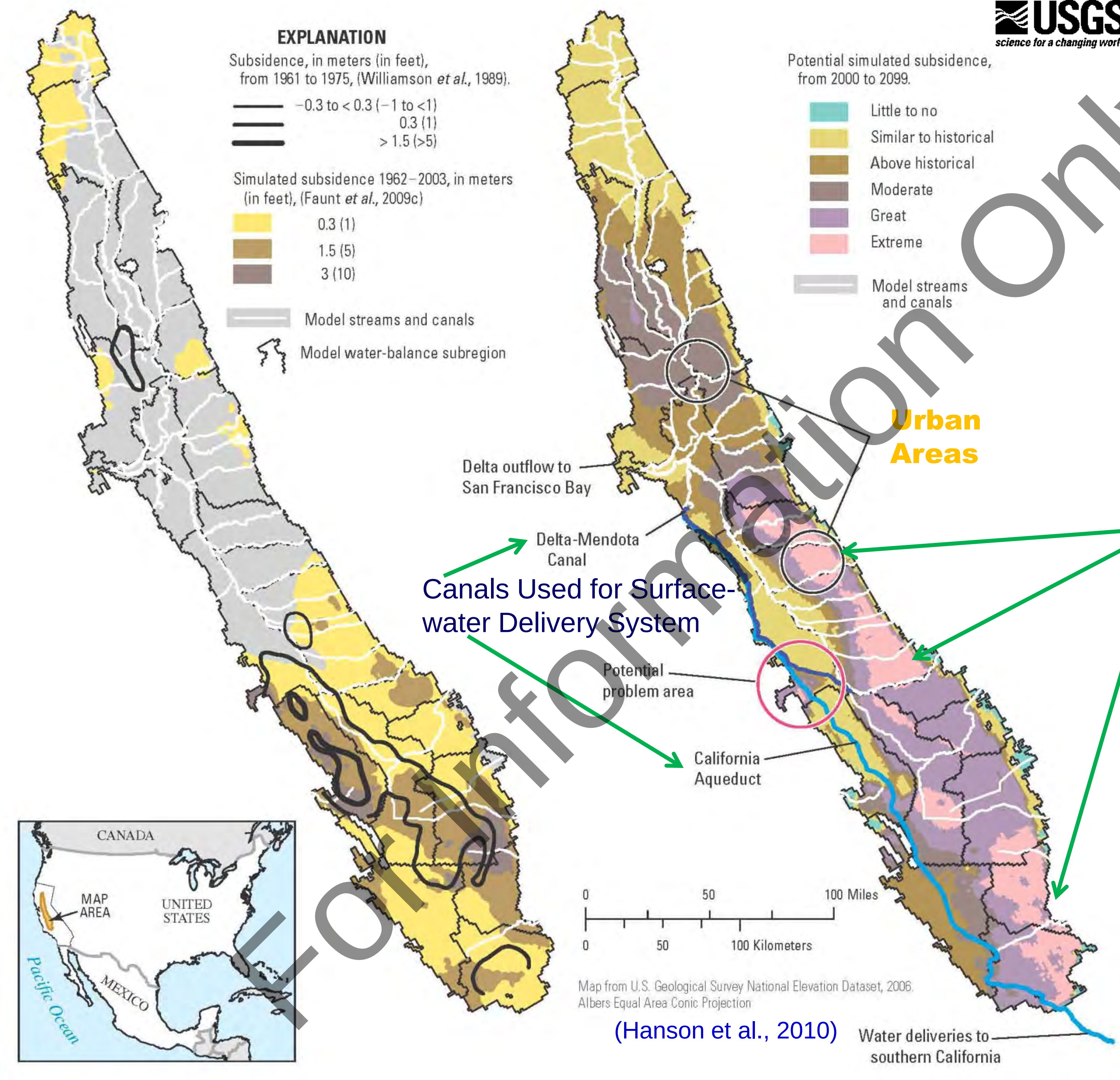
Old and New Subsidence



Renewed Subsidence in Historical Areas

Largest new Subsidence Adjacent to Sierras where Surface-water Deliveries for Irrigation become less

Additional subsidence in growing Urban areas

Summary of A2 Scenario Simulation of 21st Century

- **Increased** Groundwater Storage Depletion under A2 scenario for 21st Century in Central Valley
- **Increased** Land Subsidence throughout Central Valley and especially in the Tulare Basin and areas adjacent to Sierras (southern Central Valley)
- **Increased** streamflow infiltration and decreased groundwater outflow in the Sacramento Delta from 1-meter rise in sea level & 1.2% per year Urban Water Growth (model sensitive to even larger urban-demand growth rates!)
- **Decreased** Precipitation →Intermittent droughts in first half of century followed by sustained drought in 2nd-half of 21st Century
- **Decreased** Outflow at the Delta plus many rivers & diversions
- **Water-Use Transition** Surface-water dominated irrigation supplies to groundwater supplies with sustained drought.
- **No Operational Drought** Simulated capacity of sw/gw supply in system still greater than combined potential demand on conjunctive-use system
- **Climate Change and Increased Urban water use** →Both affect sustainability → land subsidence and reduced outflow at the Sacramento Delta

- **GCM-MHWM-CVHM Linkage Coupled physically-based, supply-constrained, and demand driven models** Basis for a Decision Support System Evaluate Outflow of streamflow at the Delta, Streamflow, Surface-water Diversions, Land Subsidence, & Drought Scenarios, Supply-&-Demand Components

- **Hydrologic projections** of a Century are more reliable in trends and changes than actual outcomes

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Today's Take-Home Messages

One Water

Linked & Integrated Models and Observation networks needed for Physcially-based Resource Analysis (Self-Updating Models → DSS & Indicators)

Sustainability, Conjunctive Use, Adaptation Controlled by Secondary effects

Management horizons may range from years-decades to more than a Century (2050 time frame may be inadequate ex. California Water Plan?)

Multiple Stressors on Resource → Climate change, Urbanization, Agricultural, Environmental

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Today's Presentation

Outlook

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Develop Tools for Integrated Flow/Transport Models & Self-Updating Models → Conjunctive-Use, Adaptation, Sustainability Analysis of Water Resources

- Remote Sensing Data-Stream Linkages → Self-Updating Models & ground-based networks
- Regional Climate Modeling → Coastal and intermontane Agricultural Regions
- Linkages to Climate Models & Analysis - Visualization Tools → Climate-In-A-Box
- Automated Analysis/Synthesis of Remote Sensing Data (ex TOPS)
- Develop Decision Support Systems

USGS Integrated Hydrologic Models

Supply-Constrained & Demand-Driven Conjunctive Use Analysis

Principal Investigator
Randy Hanson ➔
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San Diego, CA

For more information refer to ➔
USGS Office of Groundwater Software:
http://water.usgs.gov/nrp/gwsoftware/fmp/fmp.html/
USGS WEBINAR CLIMATE-CHANGE (*Hanson et al.* 3/17/2011)
(http://wwwrcamnl.wr.usgs.gov/wrdseminar/playwrd.htm?id=17mar2011)

California-Nevada Applications Program (CNAP) & The California Climate Change Center (CCCC) : http://meteora.ucsd.edu/cap/

NASA's Climate-In-A-Box: http://climateinabox.nasa.gov/

NASA's Modeling GURU: https://modelingguru.nasa.gov/index.jspa

The End? ➔ Thank You!

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