



Water Cycle Measurement Uncertainties and Droughts Analysis in California

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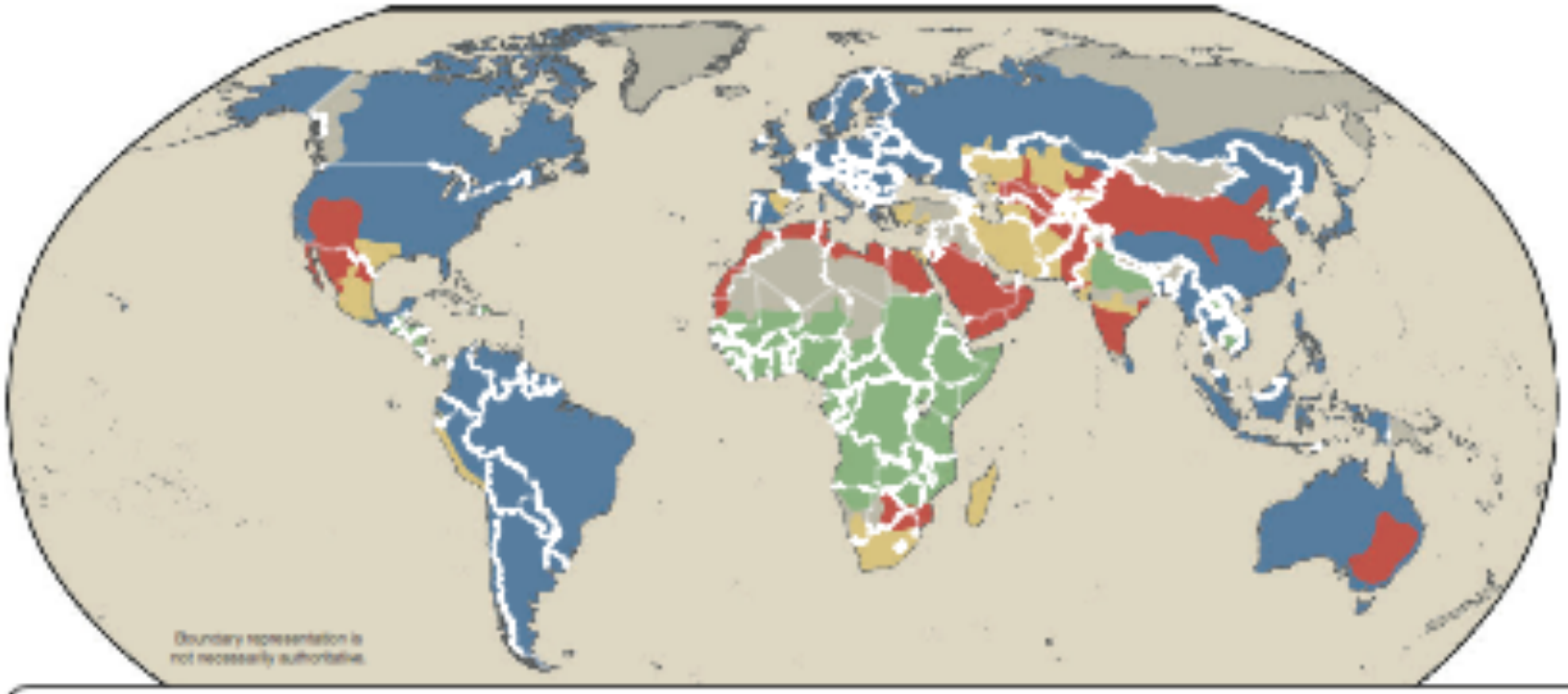
Geography Department, University of California, Berkeley

IGCP 565 Project Workshop

San Francisco, California

11 December 2008

Projected Global Water Scarcity, 2025



Physical water scarcity: More than 75% of river flows are allocated to agriculture, industries, or domestic purposes. This definition of scarcity — relating water availability to water demand — implies that dry areas are not necessarily water-scarce.

Approaching physical water scarcity: More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.

Economic water scarcity: Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Little or no water scarcity: Abundant water resources relative to use. Less than 25% of water from rivers is withdrawn for human purposes.

Not estimated

Source: International Water Management Institute.

Project 565 Key Scientific Issues

- ***Development of an integrated dynamic model for predicting daily-to-interannual geodetic signals surface mass changes;***

- ***Inversion algorithms for combined geodetic observations for surface mass changes;***

- ***Integration/assimilation of observed surface mass changes in hydrological models;***

- ***Development of products relevant for regional water management.***

Goals of the 565 Project

1. Prepare the assimilation of the GPS and GRACE observations into integrated predictive models of the hydrological cycle.

2. Focus on the interpretation of the space-geodetic observations in terms of regional groundwater and soil moisture changes.

Drought

- Meteological
  - Insufficient Net Precipitation
- Hydrologial
  - Insufficient Surface/Ground Water
- Agricultural
  - Insufficient Soil Moisture
- Socio-Economic
  - Insufficient Water Resource Supply to meet growing demands

The Total Mass Groundwater ?

One of the most difficult hydrologic cycle terms to tie down is Total Groundwater.

There is a need for increased in situ (well) and remote sensed measurements

Relative Variations have uncertainties based on how well all other terms are measured and assimilated (e.g. LDAS)

HYDROMETEOROLOGICAL DROUGHT INDICES

- Palmer Drought Severity Index (PDSI)
- Bhalme-Mooley Drought Index (BMDI)
- Crop Moisture Index (CMI)
- Agro-Hydro Potential (AHP)
- Standardized Precipitation Index (SPI)
- Effective Drought Index (EDI)
- Surface Water Supply Index (SWSI)
- Drought indices derived from flow data
- Deciles
- Percent of normal rainfall indices

DROUGHT-RELATED INIDICES DERIVED FROM REMOTE SENSED DATA

- **Normalized difference vegetation index (NDVI)**

$$NDVI = (\lambda_{NIR} - \lambda_{red}) / (\lambda_{NIR} + \lambda_{red})$$

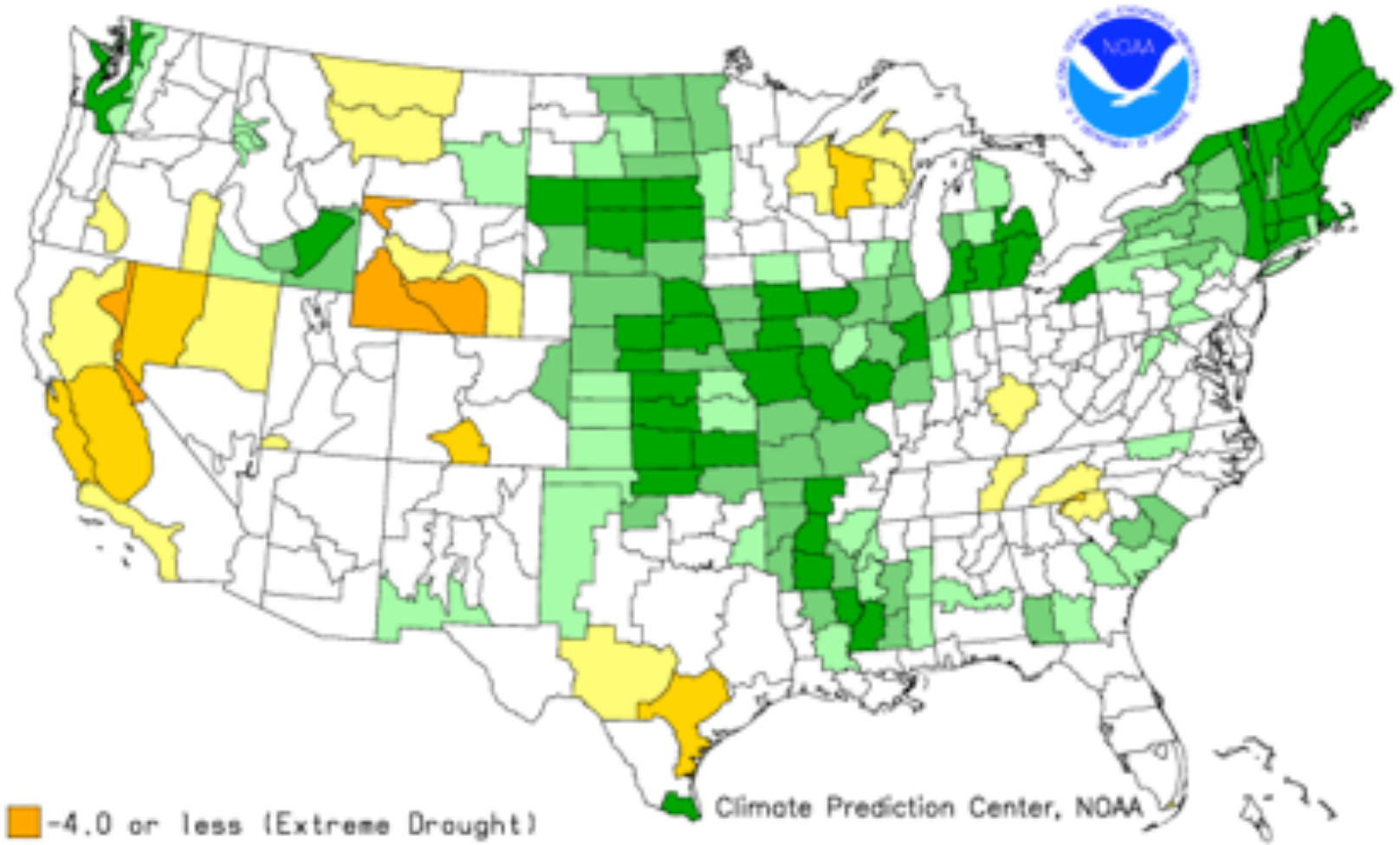
$$Drought\ \ severity = NDVI_i - NDVI_{mean,m}$$

- **Enhanced vegetation index (EVI)**
- **Vegetation condition index (VCI)**
- **Temperature condition index (TCI)**

Drought Severity Index by Division

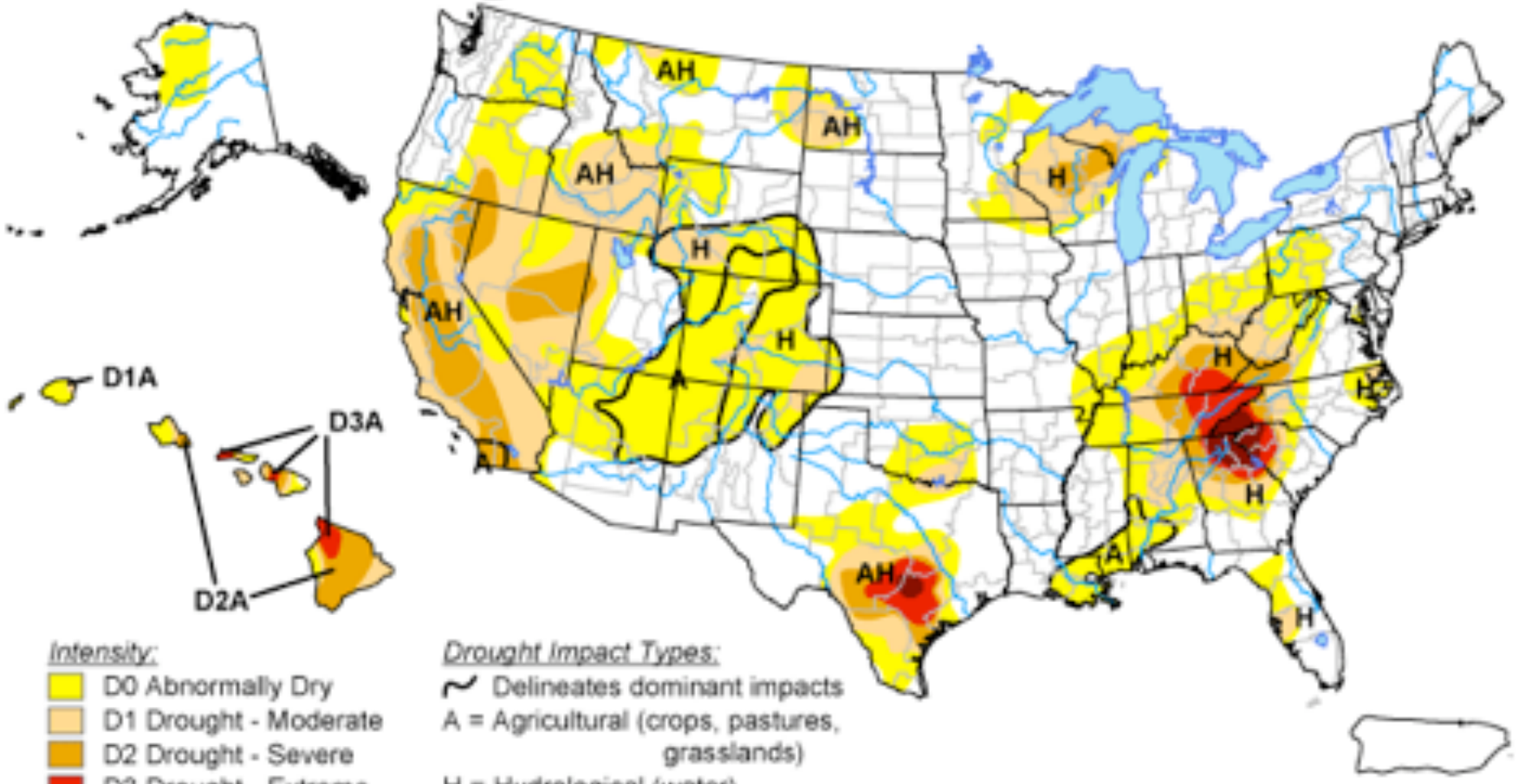
Weekly Value for Period Ending DEC 6, 2008

Long Term Palmer



U.S. Drought Monitor

December 2, 2008
Valid 8 a.m. EST



Intensity:
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:
- Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

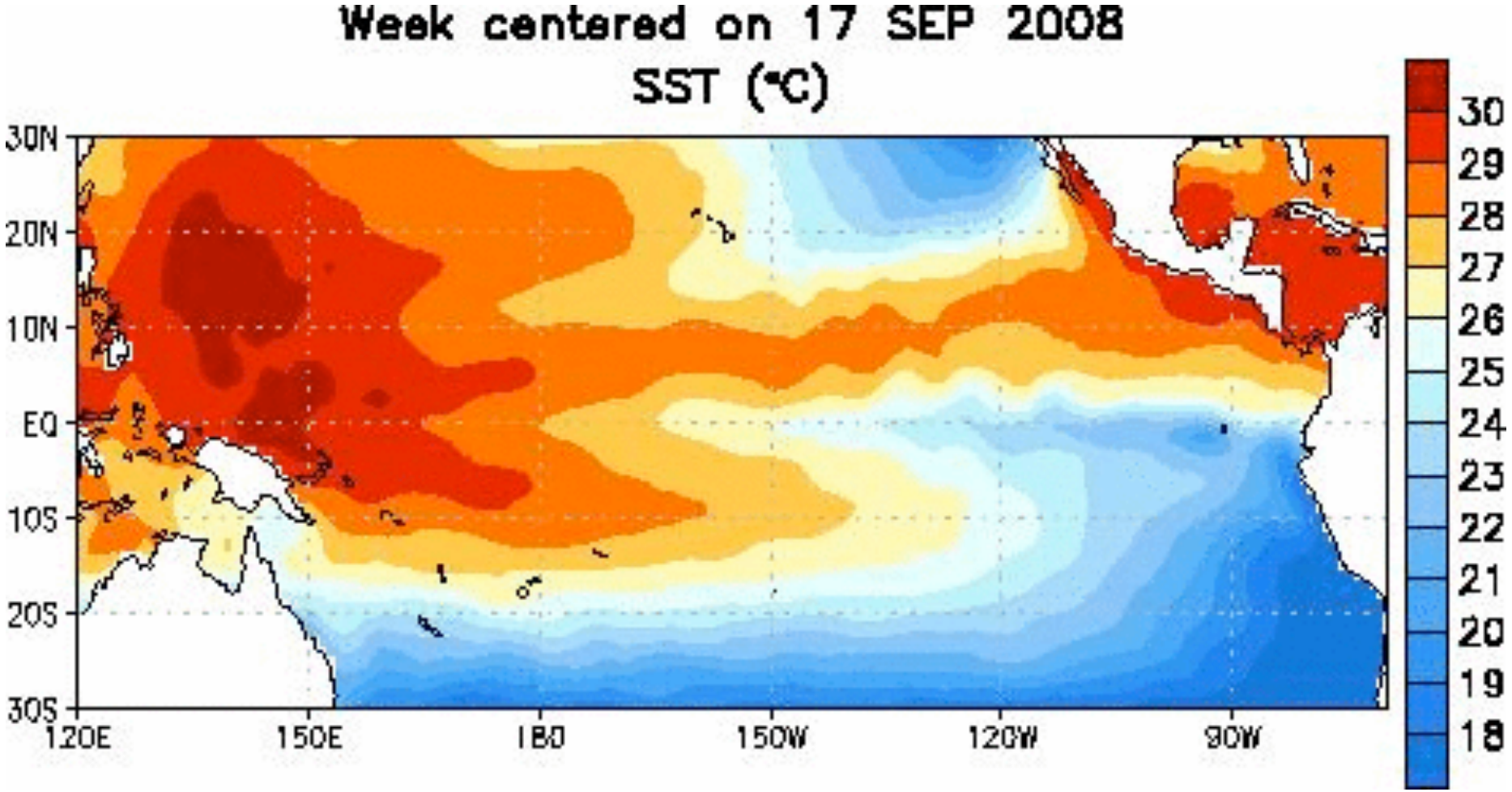
http://drought.unl.edu/dm

Released Thursday, December 4, 2008

Authors: Michael Brewer/Liz Love-Brotak, NOAA/NESDIS/NCDC

Causes for Hydrometeological Drought

- Forced by Sea Surface Temperature (e.g. Australia, Sub-Sahara, Atlanta, Georgia)
- Large-Scale Circulation Change
  - Shifts in Jets and Storm Tracks (e.g. LLJ shift)
- Atmospheric Patterns – Blocking (e.g.
- A Warming Planet
  - descreasing snowpack, snow/rain ratio


Week centered on 17 SEP 2008
SST (°C)
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
30
29
28
27
26
25
24
23
22
21
20
19
18

Buoy Monitoring, Truthing, and Uncertainty

Buoy Data - collected from the Global Telecommunication System (GTS)

- Quality Control Centers are UKMO, NCEP, ECMWF, CMM, SAWB, BOM
- Statistics computed exclude gross errors (i.e. observations departing from the background field)
- Spatial density and frequency of measurement
- Calibration among different Buoys

Satellite Monitoring SSTs for Drought

Integrated SST Data Products:

- Global High-Resolution SST Pilot Project (GHRSST-PP)
  - Global Ocean Data Assimilation Experiment (GODAE) High Resolution SST Pilot Project GHRSST-PP

- ESA Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR/ATSR-4)

GHRSST-PP v1.0 Metrics

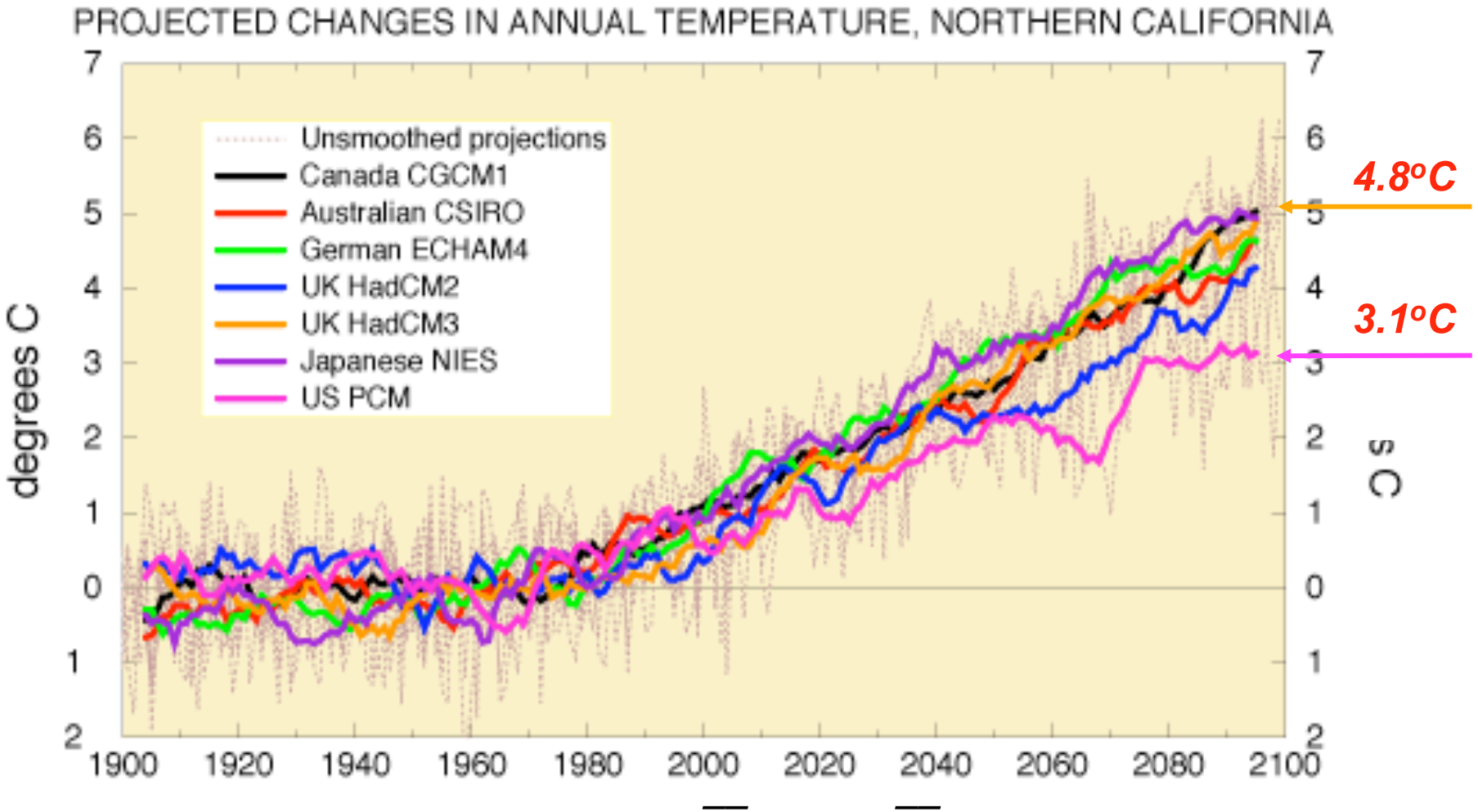
1. The timely delivery of data to users, to GDAC, and to RDACs.
2. The accuracy of SST fields (Number of in situ data points available for SST validation, rms, and bias).
3. The number of satellite data sets (orbits, overpasses) available to GDAC.
4. The extent to which all geographical areas covered.
5. The production of DDS: areas covered, timely on-line access to DDSs.6.Access to in situ data via MDB records. Links to DDS.

Japanese Space Exploration Agency (JAXA)

- Global Change Observation Mission Water (GCOM-W) Advanced Microwave Scanning Radiometer II (AMSR-II)

- Global Change Observation Mission - Climate (GCOM-C) Second-generation Global Imager (SGLI)

Global Climate Model Projections

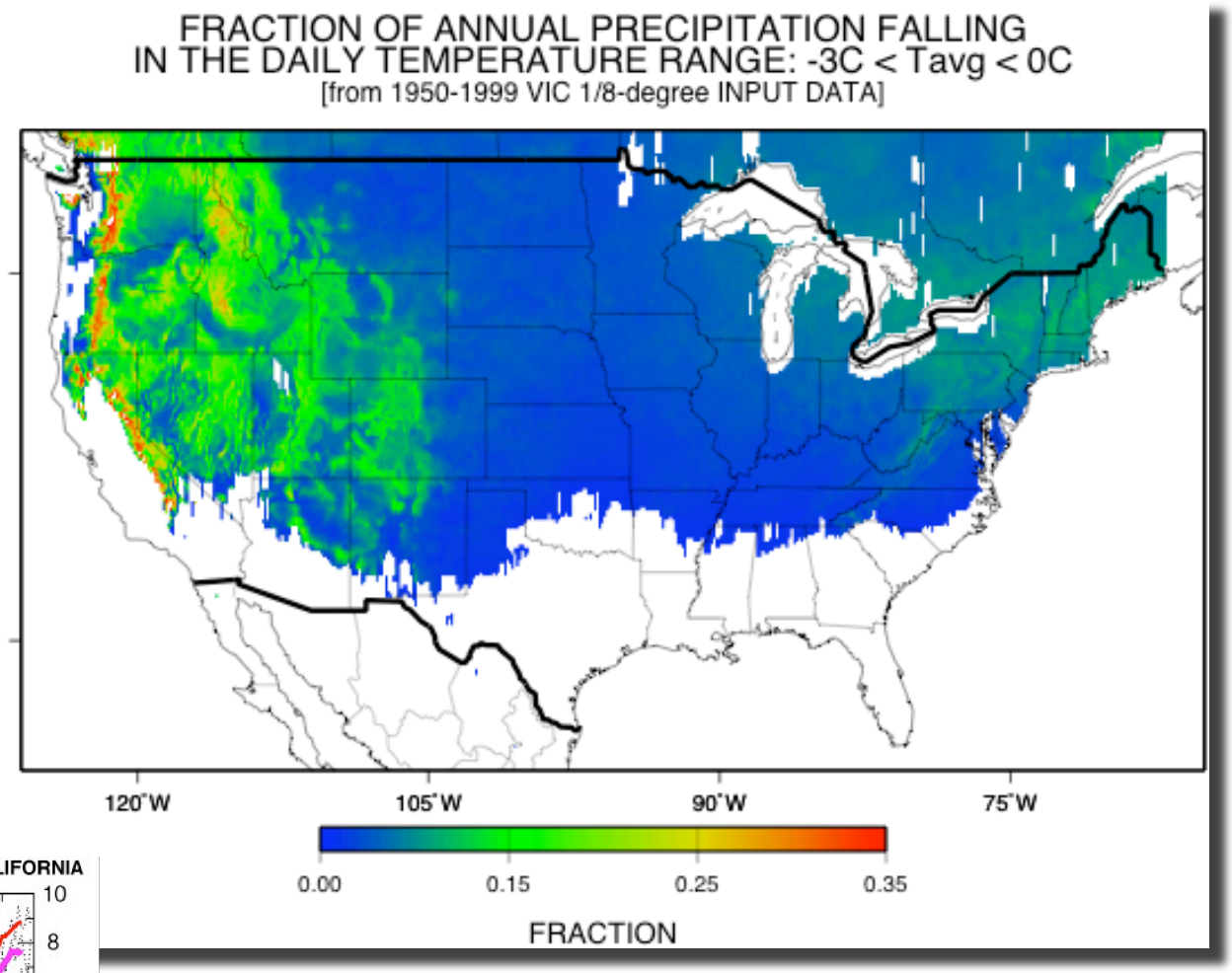


Temperature Sensitivity: $\overline{T}_{2070\text{-}2099} - \overline{T}_{1961\text{-}1990}$

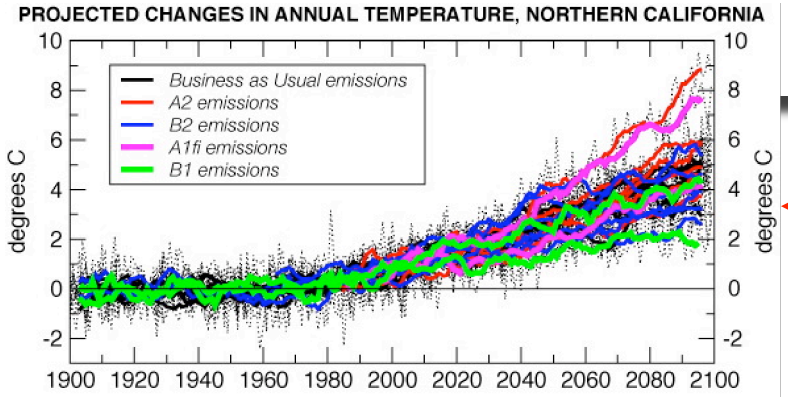
PCM Low Sensitivity ***HadCM3 High Sensitivity***

SENSITIVITY OF +3ºC ON SNOWFED HYDROCLIMATE

- **Fraction of historic annual precipitation with average temperatures just below freezing**
- **Cascades and Sierra Nevada are the most sensitive snow water resource regions in the US to 3ºC warming**



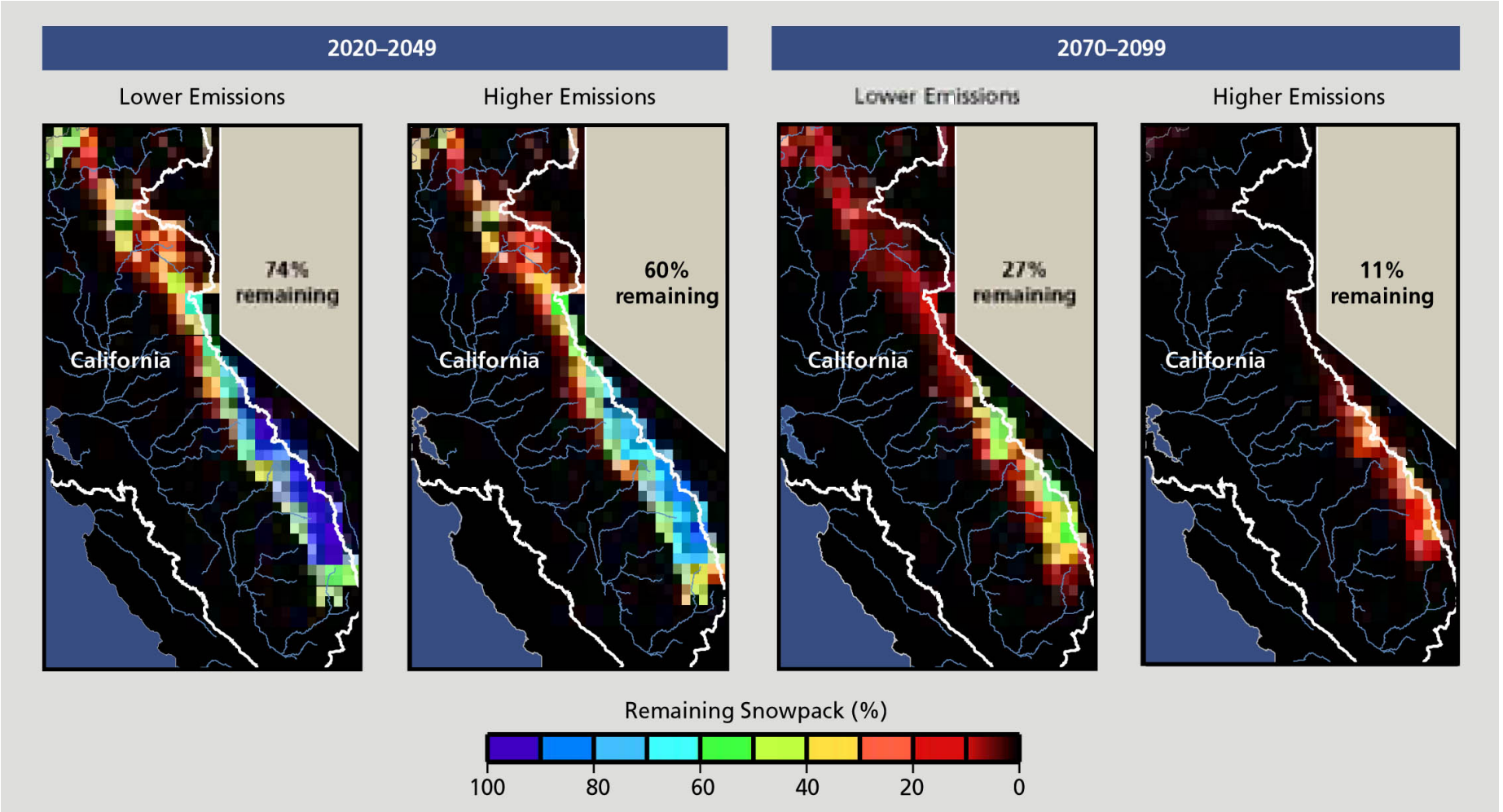
Less vulnerable — More vulnerable



← +3

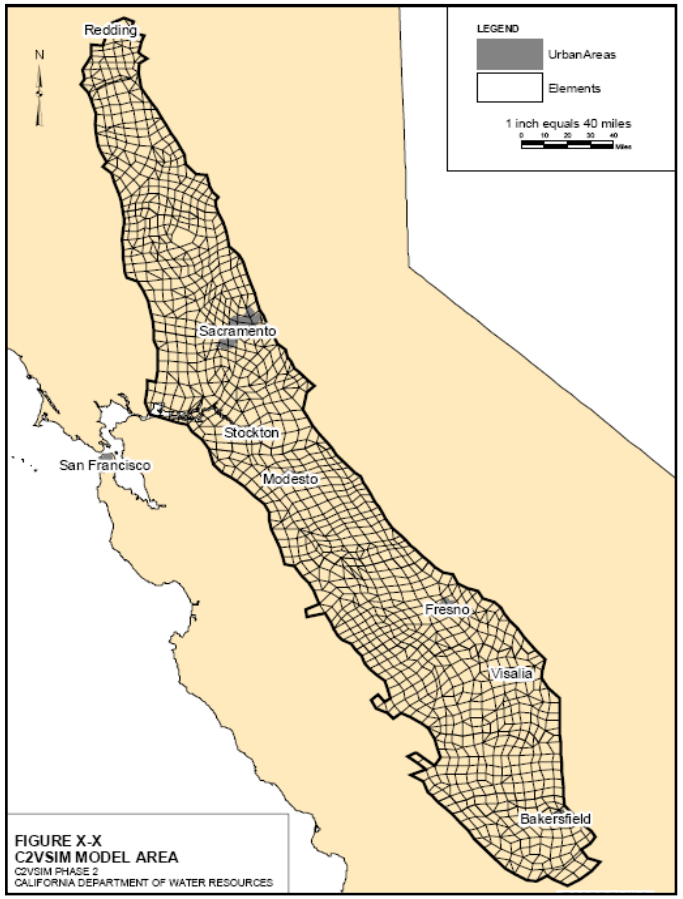
Computed from UW's VIC model daily INPUTS
Courtesy Mike Dettinger.

Diminishing Sierra Snowpack
% Remaining, Relative to 1961-1990



California Assessment Report 2004

Snowpack Reduction Impacts on California Groundwater Water Infrastructure Using C2VSIM





Domain: ~ 20,000 square miles

Drought Experiments

- Approach:
  - Recreate drought scenarios considering historic data

- Managed Surface Water Drought Scenarios
  - 10 year spin-up;
  - Duration: 10, 20, 30, 60 year managed droughts
  - Intensity: Dry, Very Dry, Critical 30, 50, 70 effective reduction
  - 30 year rebound period

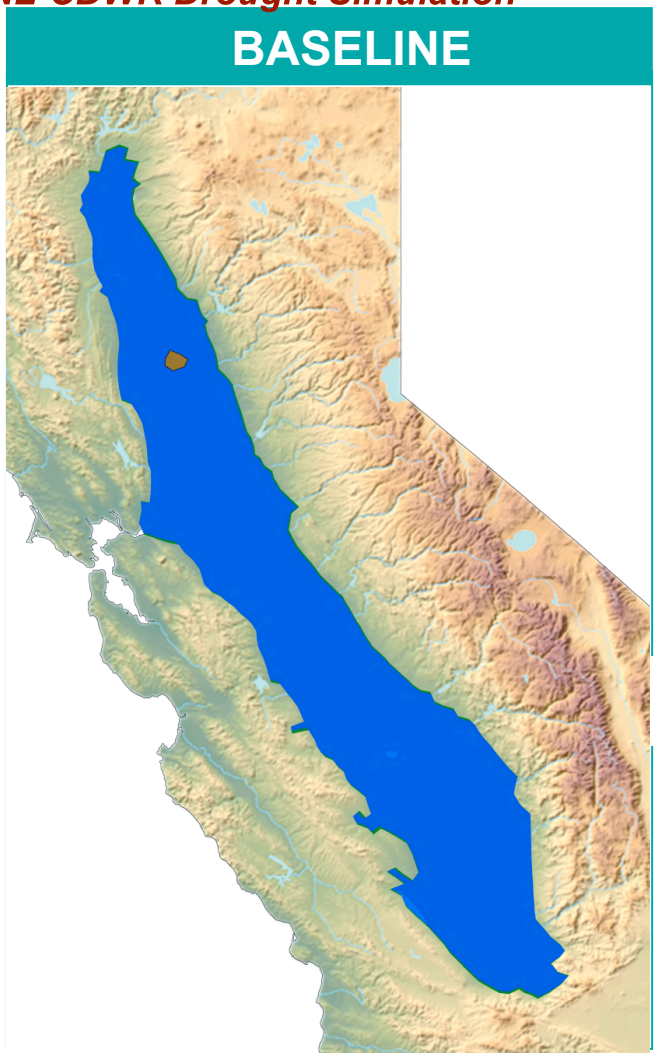
  - All simulations used fixed 1973-2003 precipitation, urban demands, cropping etc.

Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

- ***Climate simulations using the IPCC SRES output indicates California Snowpack will be reduced by 60-90% by 2100.***

- ***Simulating drought scenarios acts as an analogue to climate warming and provides us with a means to analyze impacts.***

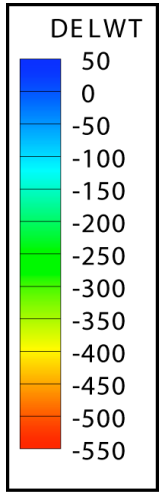


- **Baseline - no surface water reduction**

- **Drought - 30 - 70 percent surface water reduction**

- **All simulations used fixed 1973-2003 precipitation, urban demands, cropping etc.**

Relative WT Change (Feet)

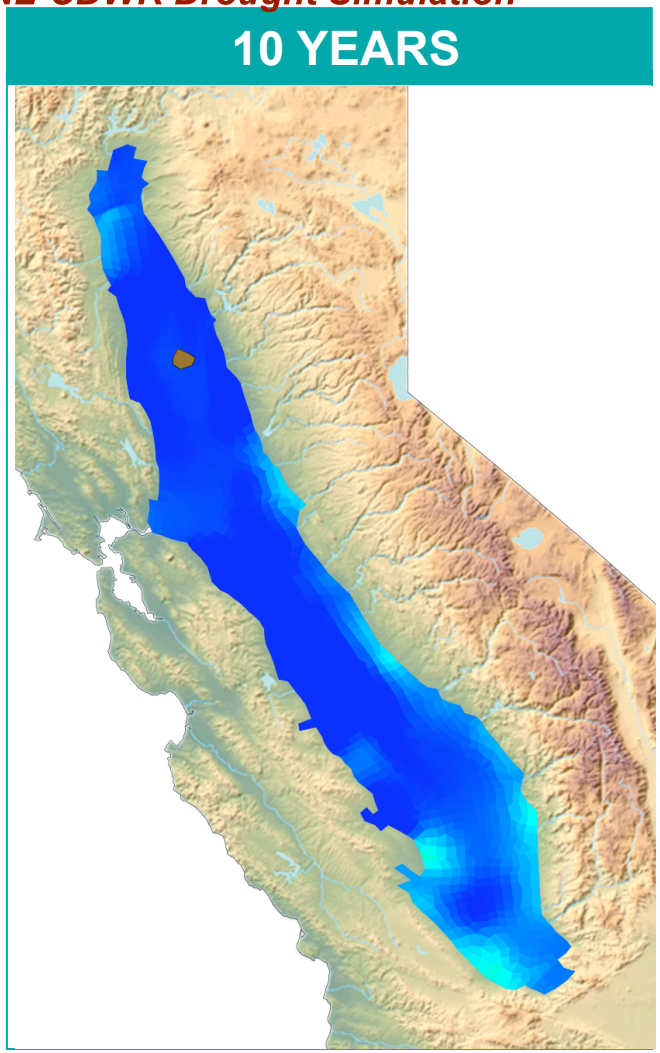


Central Valley Water Table 'Relative' Response

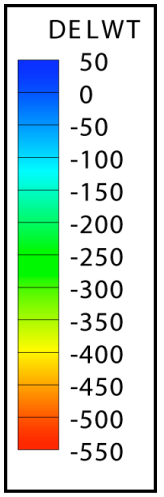
Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)



Miller et al. 2006

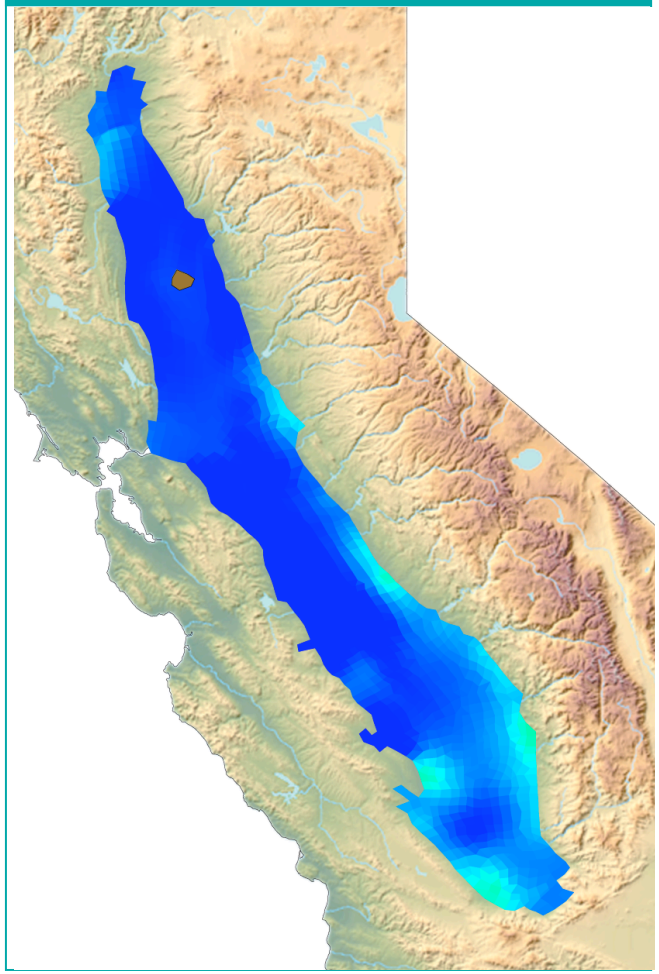
Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

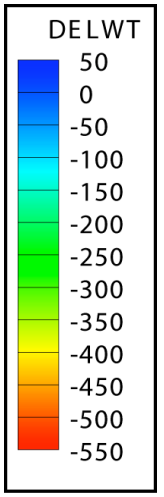
20 YEARS

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)

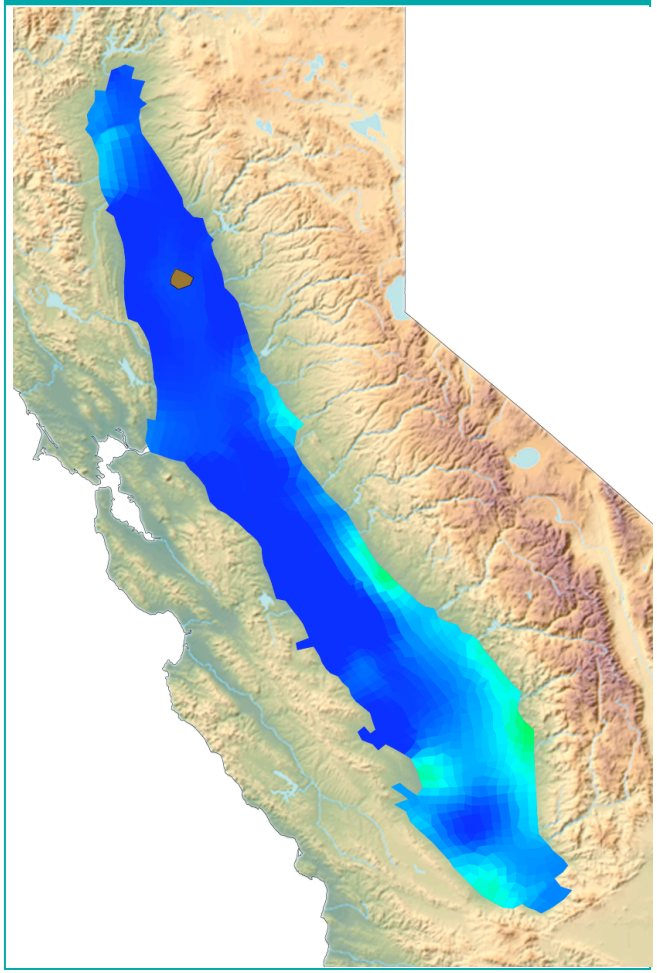


Miller et al. 2006

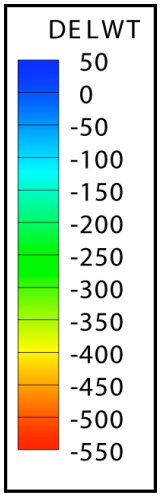
Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

30 YEARS



Relative WT Change
(Feet)



DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

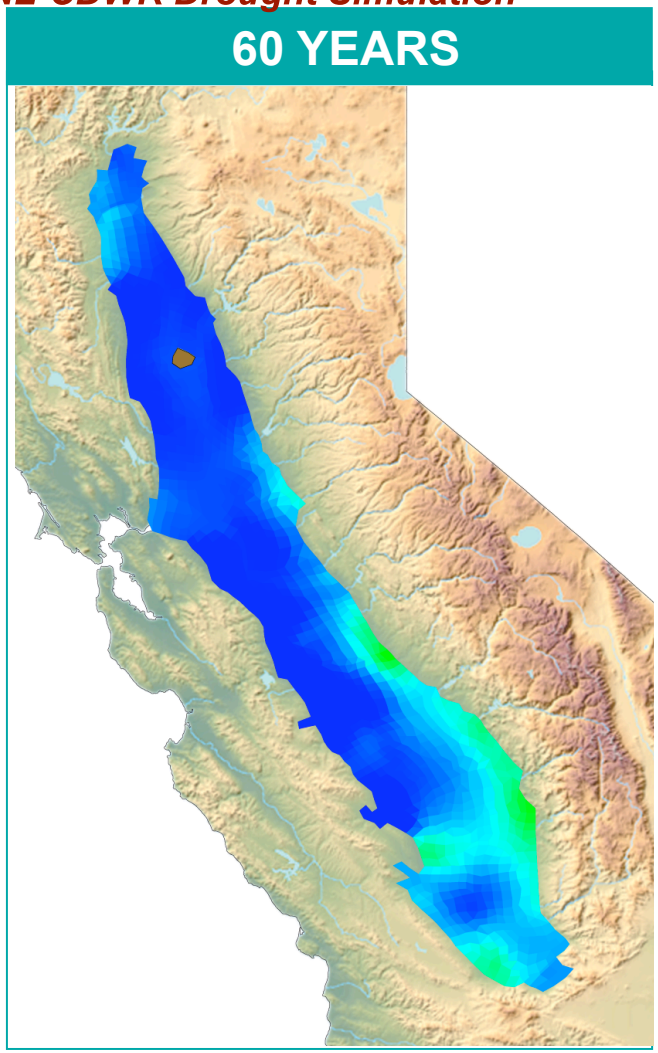
Miller et al. 2006

Case II: Initial Central Valley Water Table 'Relative' Response

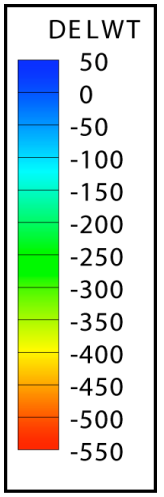
Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)



Miller et al. 2006

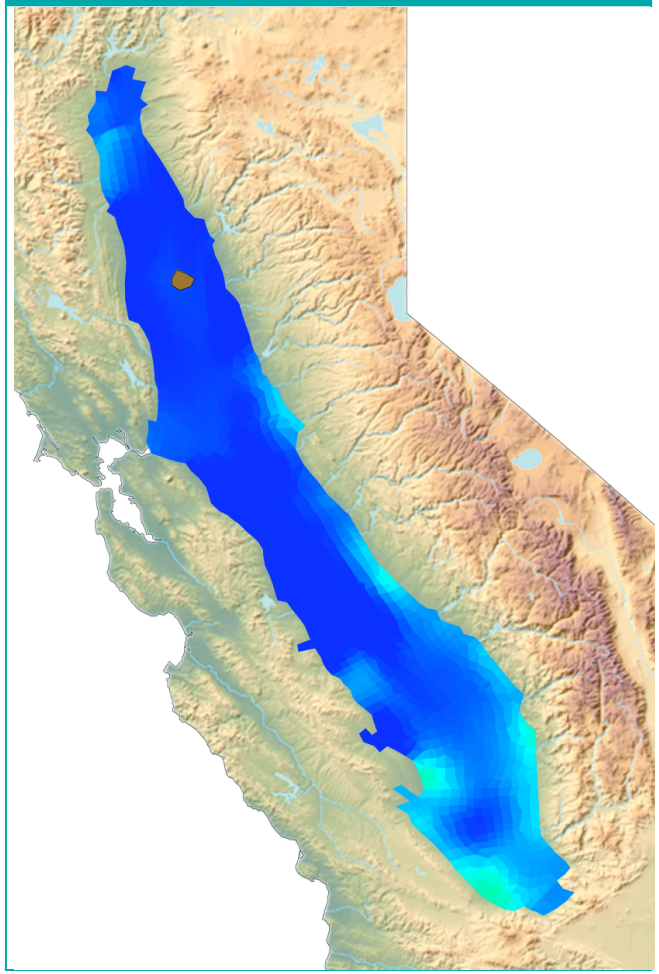
Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

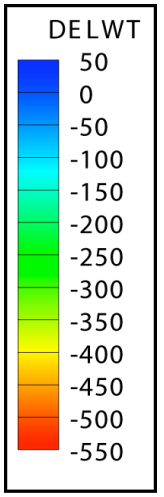
VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

10 YEARS



Relative WT Change (Feet)



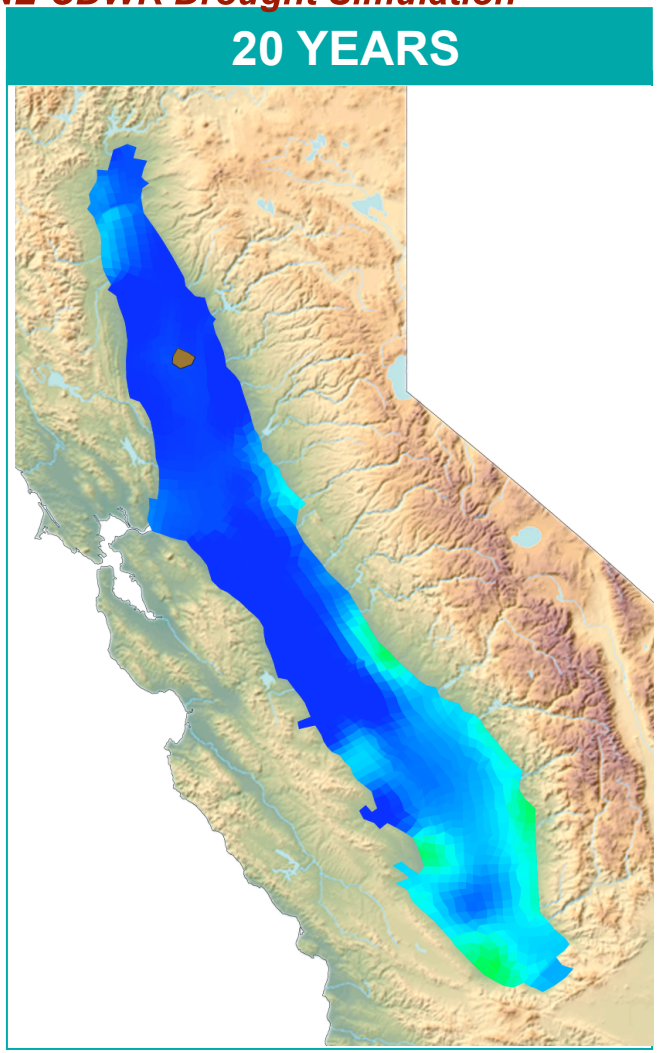
Miller et al. 2006

Central Valley Water Table 'Relative' Response

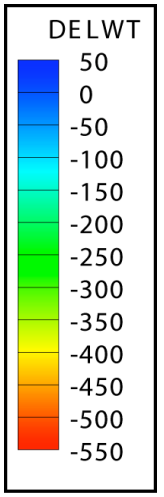
Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)



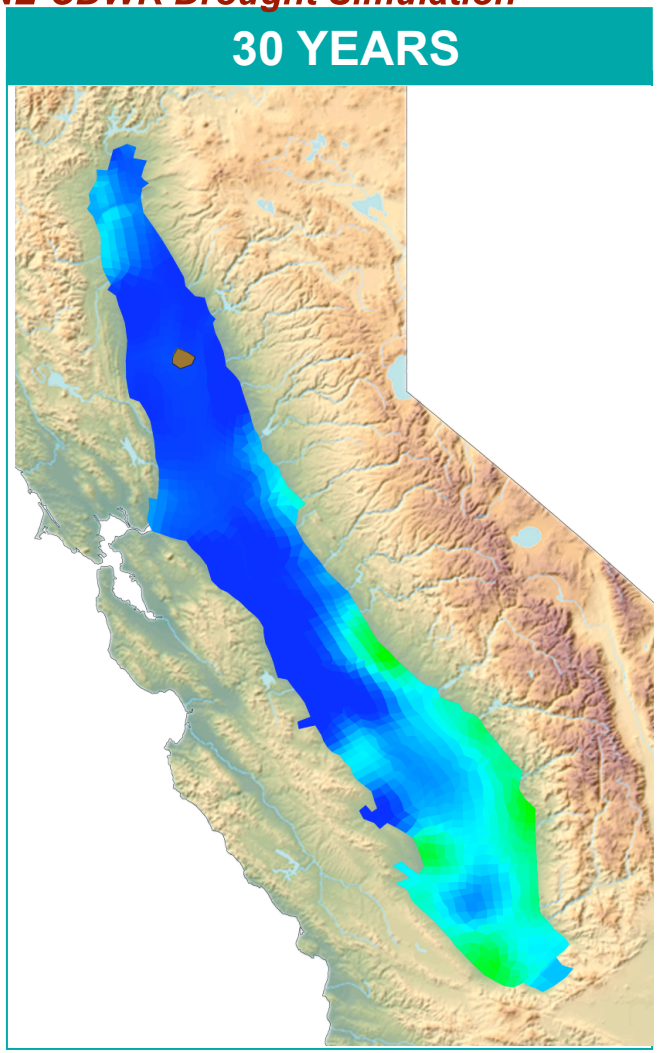
Miller et al. 2006

Central Valley Water Table 'Relative' Response

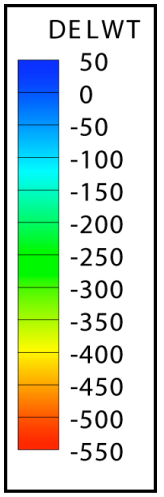
Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)



Miller et al. 2006

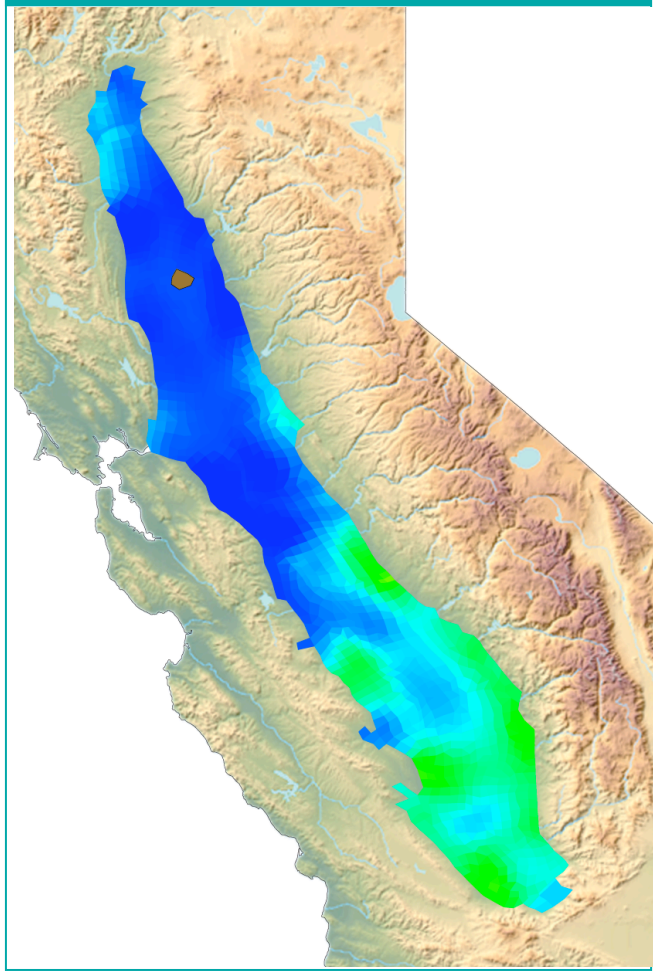
Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

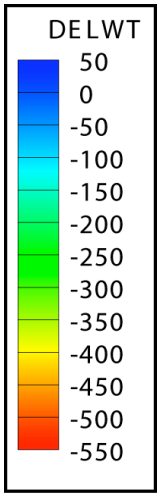
60 YEARS

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)



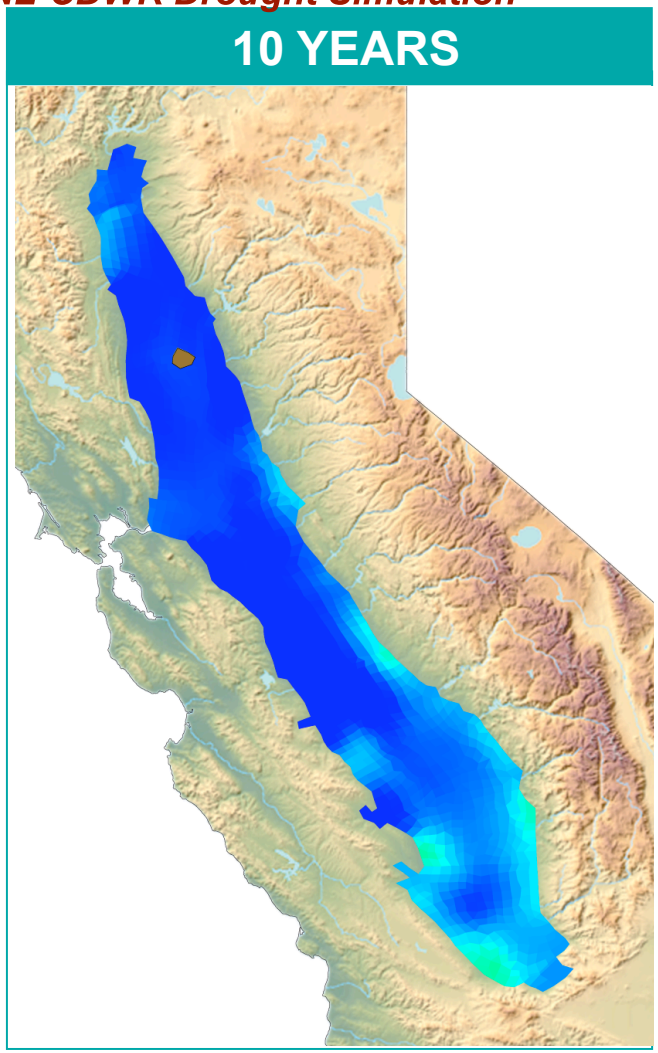
Miller et al. 2006

Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Miller et al. 2006

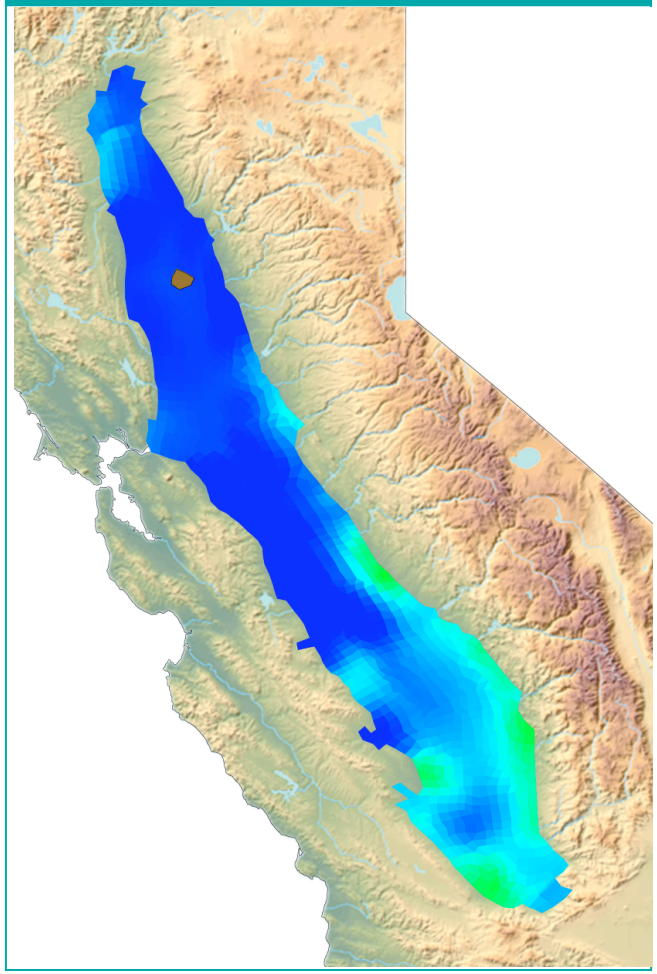
Central Valley Water Table 'Relative' Response

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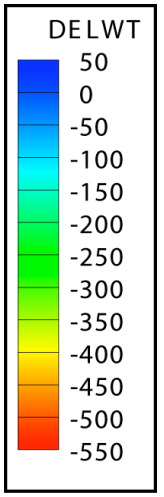
CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

20 YEARS



Relative WT Change (Feet)



Miller et al. 2006

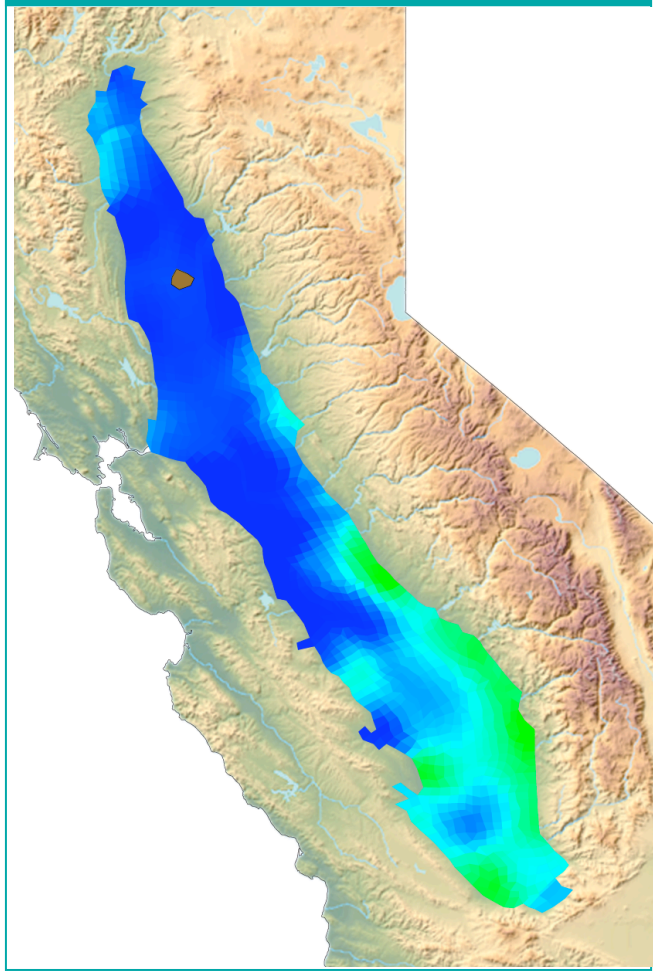
Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

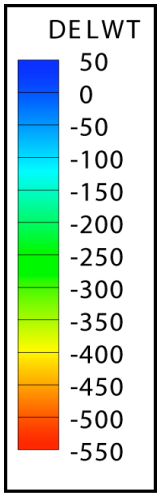
CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

30 YEARS



Relative WT Change (Feet)



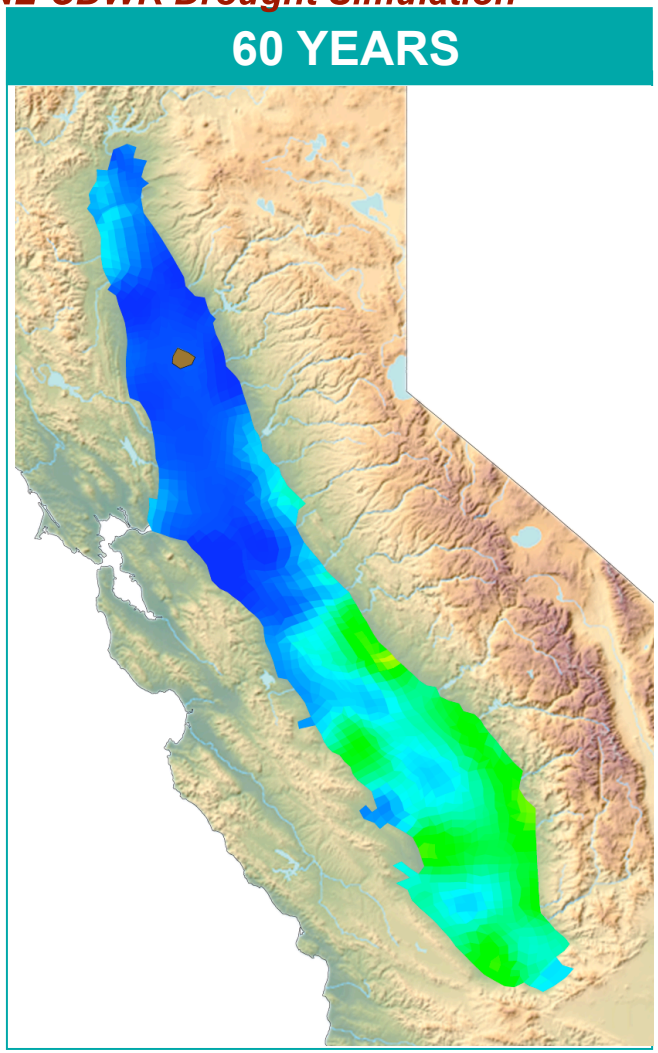
Miller et al. 2006

Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

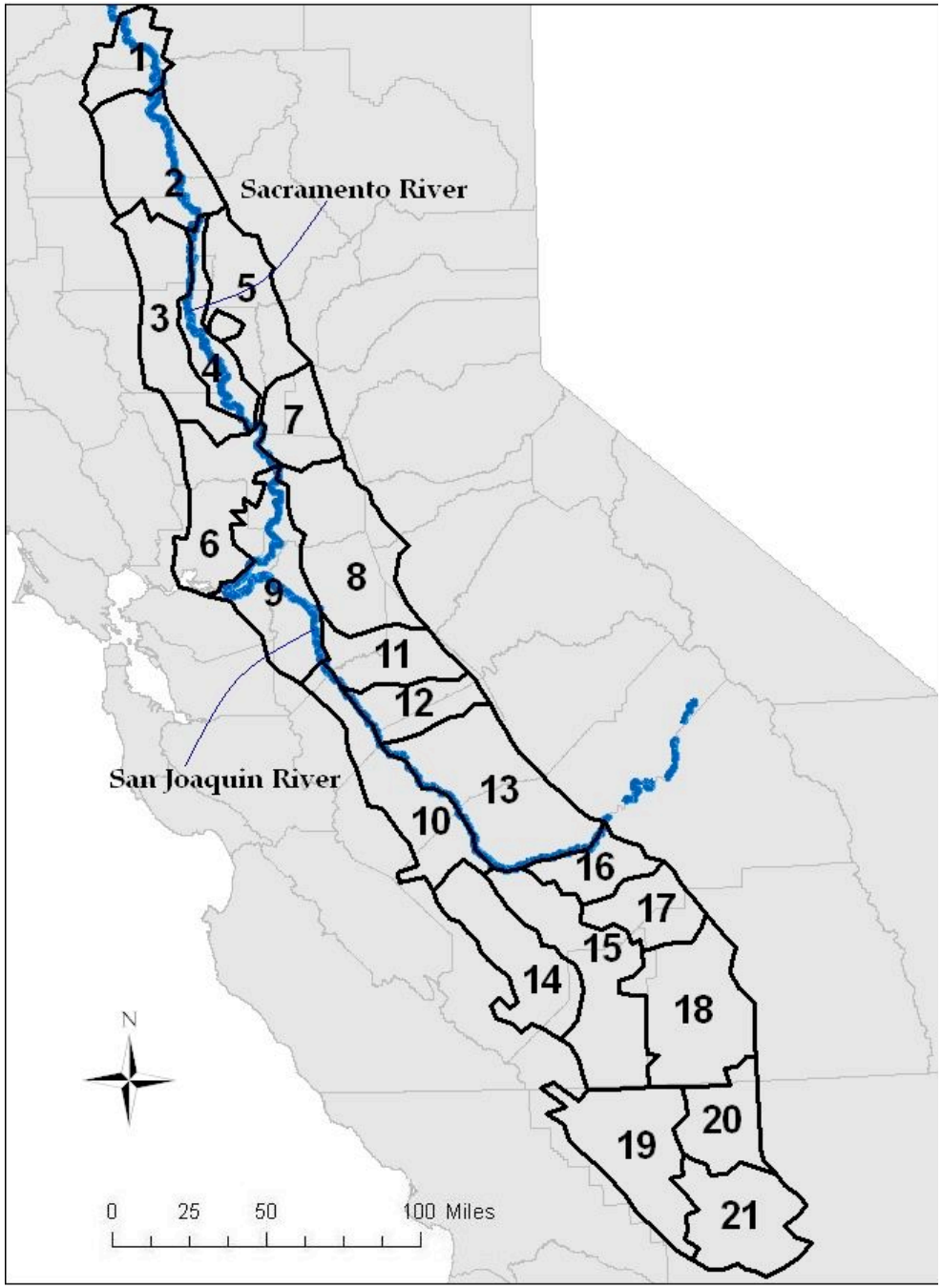
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70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

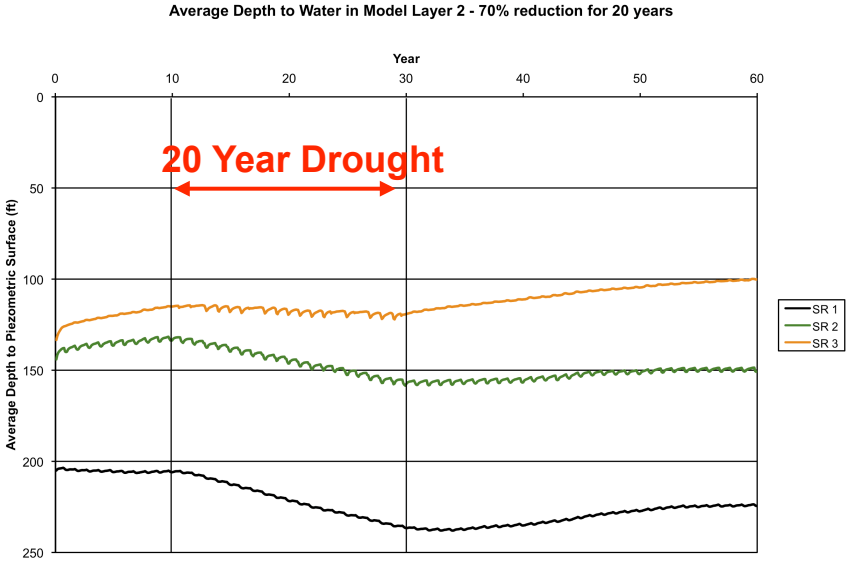


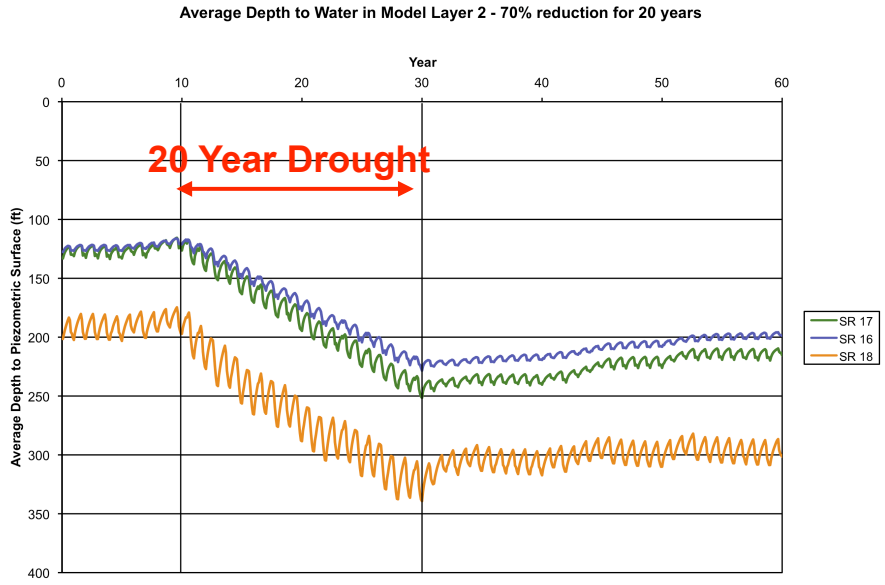
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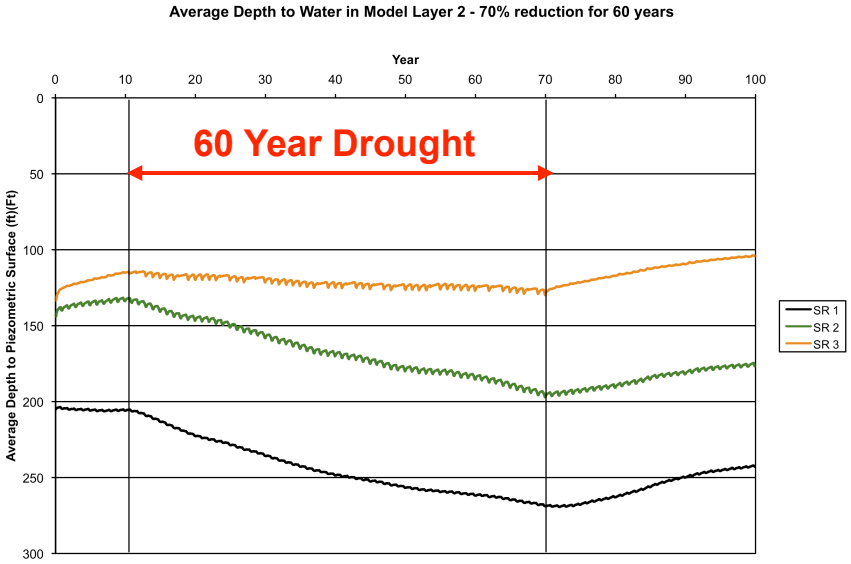
C2VSIM Sub-Regions

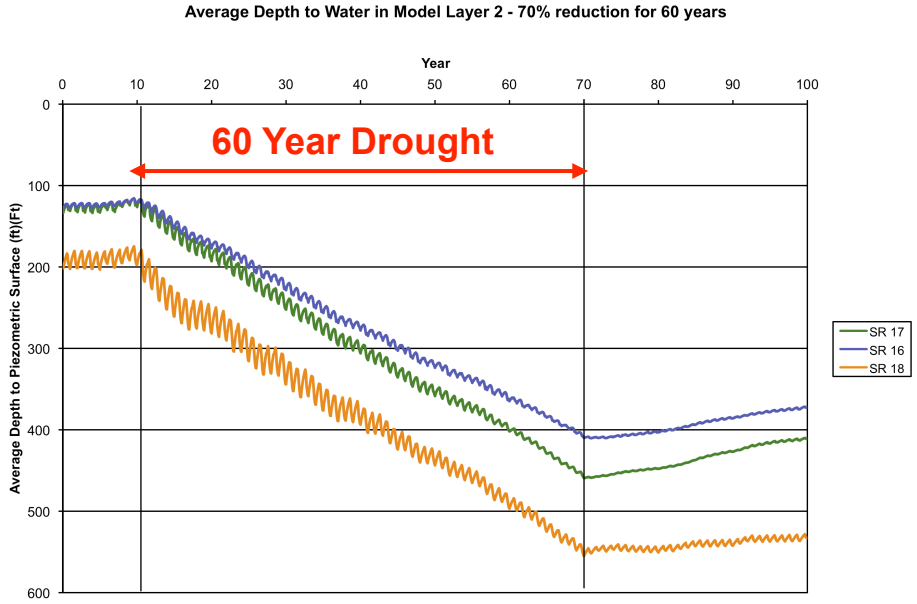


Critical (70 % Reduction)









Impact Drought on Deliveries

	Base Period	Severe drought Impact	Light drought impact
	(maf/y)	maf/y	maf/y
Sacramento	3.84	-0.81	0.27
San Joaquin	2.38	-1.04	-0.32
Tulare	2.92	-2.06	-1.20
Central Valley	10.65	-3.78	-1.07
Change (%)		-36%	-10%

	Base Period	Severe drought Impact	Light drought impact
	(af/a/year	af/a/y	af/a/y
Sacramento	1.04	-0.22	0.07
San Joaquin	0.97	-0.42	-0.13
Tulare	0.58	-0.41	-0.24
Central Valley	0.83	-0.30	-0.08
Change (%)		-36%	-10%

Impact Drought on Pumping

C2VSIM, fixed crop demand

	Base Period (maf/y)	Severe drought Impact maf/y	Light drought impact maf/y
Sacramento	0.62	0.36	0.02
San Joaquin	0.98	1.24	0.51
Tulare	4.26	2.92	1.11
Central Valley	6.30	4.64	1.69
Change (%)		74%	27%

	Base Period (ft/year)	Severe drought Impact (ft/year)	Light drought impact (ft/year)
Sacramento	0.17	0.10	0.00
San Joaquin	0.40	0.51	0.21
Tulare	0.85	0.58	0.22
Central Valley	0.49	0.36	0.13
Change (%)		74%	27%

Impact Drought on Stream Flows

C2VSIM, fixed crop demand

	Base Period (ft/year)	Severe drought Impact (ft/year)	Light drought impact (ft/year)
Sacramento	-0.44	0.14	-0.07
San Joaquin	-0.17	0.21	0.02
Tulare	0.08	-0.02	0.01
Central Valley	-0.18	0.07	-0.02
Change (%)		-38%	13%

Impact Drought on Recharge

C2VSIM, fixed crop demand

	Base Period (ft/year)	Severe drought Impact (ft/year)	Light drought impact (ft/year)
Sacramento	0.73	-0.42	-0.19
San Joaquin	0.89	-0.39	-0.15
Tulare	0.77	-0.26	-0.07
Central Valley	0.76	-0.31	-0.12
Change (%)		-41%	-16%

Impact Drought on Storage

C2VSIM, fixed crop demand

	Base Period (ft/year)	Severe drought Impact (ft/year)	Light drought impact (ft/year)
Sacramento	0.24	-0.35	-0.26
San Joaquin	0.26	-0.67	-0.32
Tulare	0.02	-0.84	-0.28
Central Valley	0.16	-0.60	-0.28

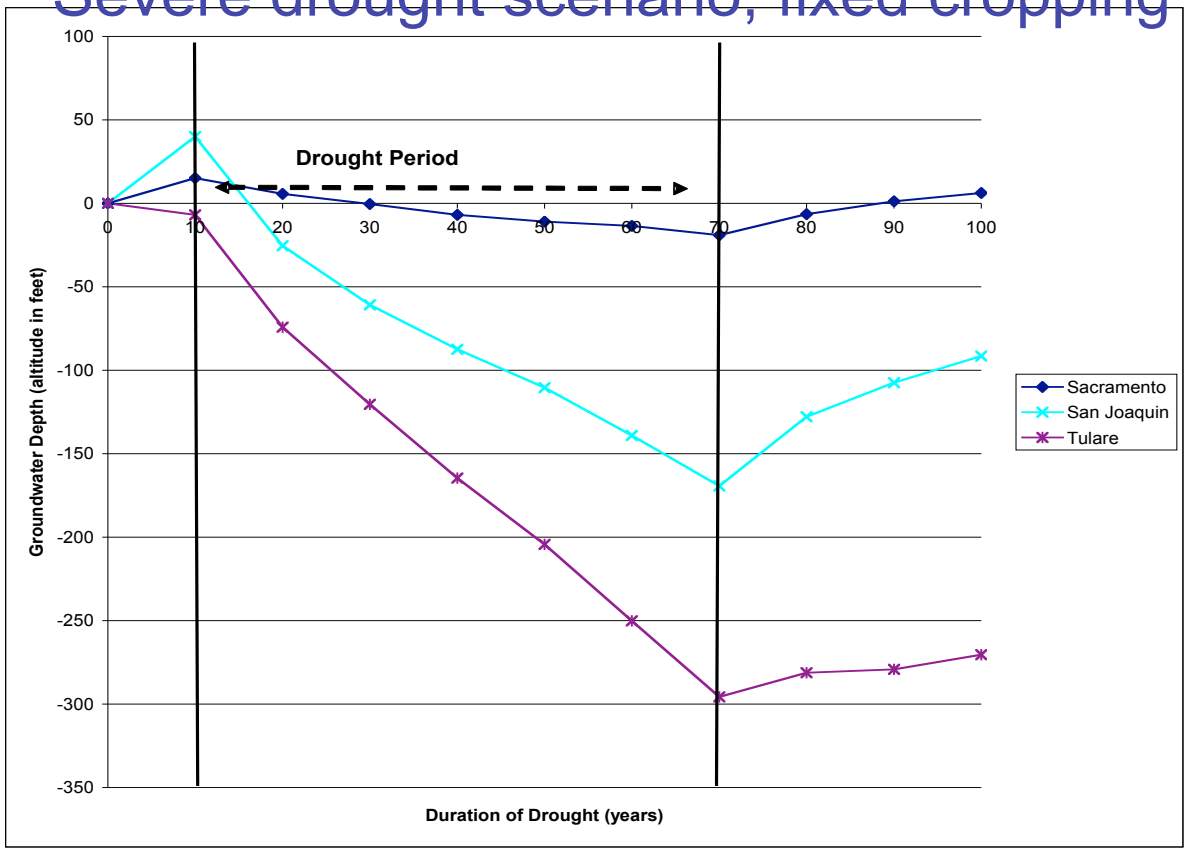
Impact Drought on Groundwater

C2VSIM, fixed crop demand

	Base Period (ft/year)	Severe drought Impact (ft/year)	Light drought impact af/a/y
Sacramento	1.52	-2.09	-1.64
San Joaquin	1.63	-5.12	-2.40
Tulare	0.11	-4.93	-1.65
Central Valley	0.98	-3.79	-1.81

Decline in Groundwater Levels

Severe drought scenario, fixed cropping

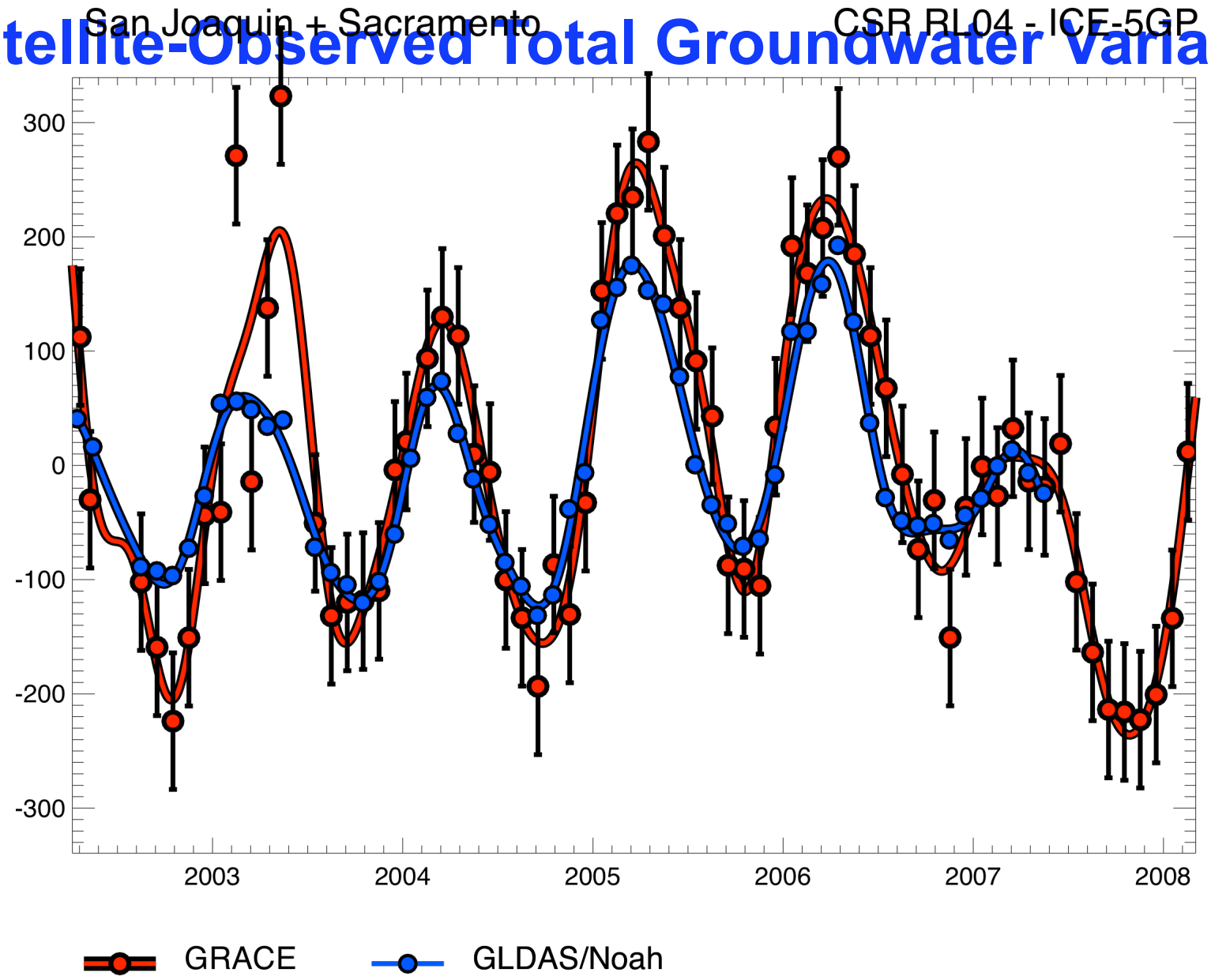


- **C2VSIM and ALL water allocation models on this scale are only partially verified.**
- **Many empirical parameters are tuned.**

Qualifiers

- C2VSIM and ALL water allocation models are only partially verified. Many empirical parameters are tuned.
- The groundwater processes lack sufficient physical descriptions.
- Groundwater total mass and variation is not known.
- Pumping is based on a limited available demand record.
- Demand is fixed and agriculture does not shift with change in supply.

Satellite-Observed Total Groundwater Variations



Conclusions

- **Drought monitoring is well advanced**
- **Drought forecasting lead time is sufficiently advanced**
- **Uncertainties range from data density to predictability of atmospheric blocking patterns**
- **In this case study droughts were simulated for 10 - 60 years**
- **Uncertainties are primarily the total groundwater variation**
- **To tie down drought response we are testing the Sacramento-San Joaquin Basin well data with GRACE data**

Conclusions

- **Main uncertainty is the spatial and temperal scale of GRACE**
- **Assimilation of GRACE and GPS together into surface-groundwater models will ring higher spatial and temporal resolution**
- **This will need to be in conjunction with well data and interpolation techniques**