Climate Change Impacts on Subsurface Hydrology, Crop Production, Water Use, and Salinity in San Joaquin Valley, CA

(DWR-UC Workshop on Climate Change Impacts, January 26, 2009)

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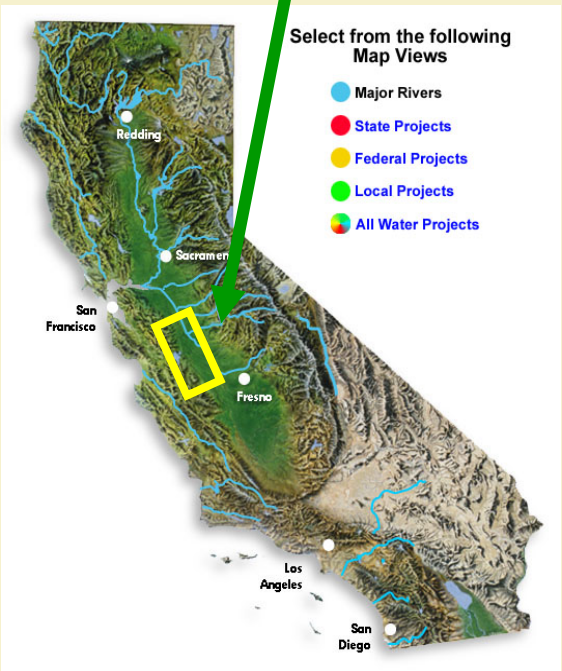


Objectives: 5-year modeling & sensitivity study

- Develop and apply hydro-salinity model capable of predicting long-term impact of water and land management decisions at the basin scale

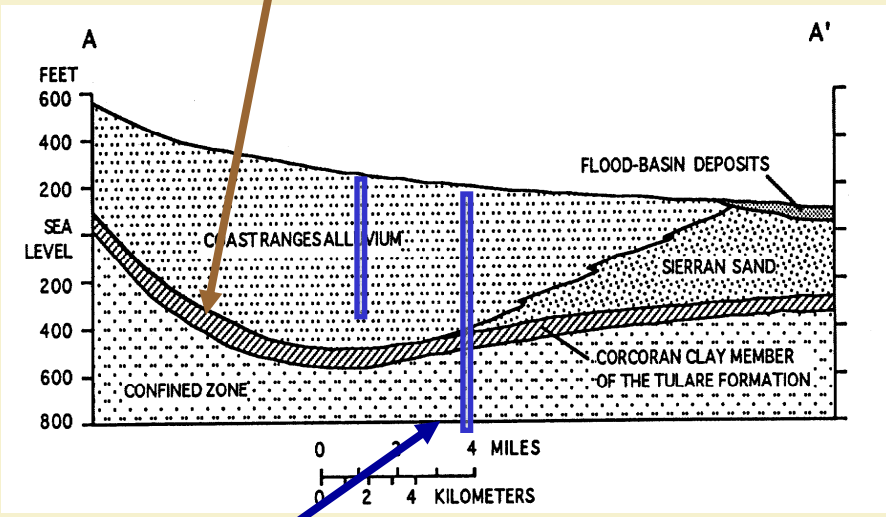
  few slides;

- Retrospective of a 60-year reconstruction (simulation) of historical changes (since 1940) in groundwater levels, and soil and groundwater salinity - few slides;

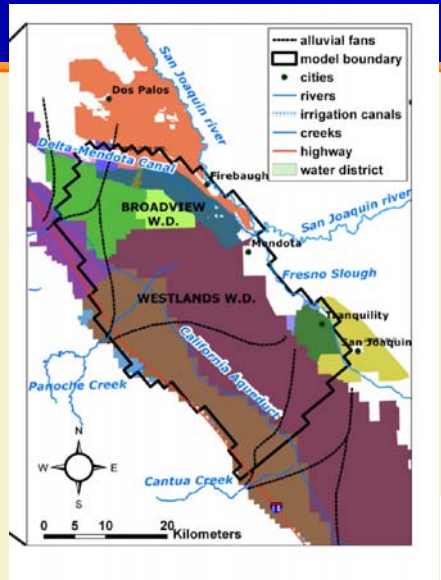
- Evaluate impacts of 100 years of climate change on crop water requirements, soil and groundwater salinity – focus of today.

Regional flow domain (Belitz et al., 1993) of western San Joaquin Valley

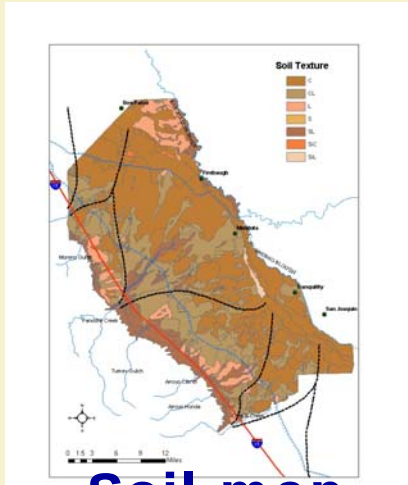
Three-dimensional model domain, bounded by <u>Corcoran clay</u> at the bottom



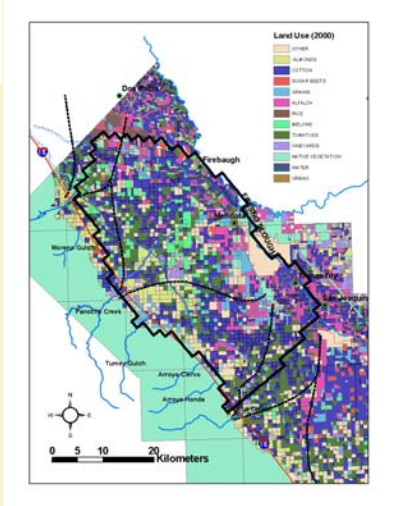
<u>Groundwater pumping</u> both above (unconfined) and below (confined) clay



- 1,400 km^2
- 13 Water Districts



Soil map



Crop map

MOD-HMS: Variably-saturated flow equation

Vadose zone is fully coupled with groundwater

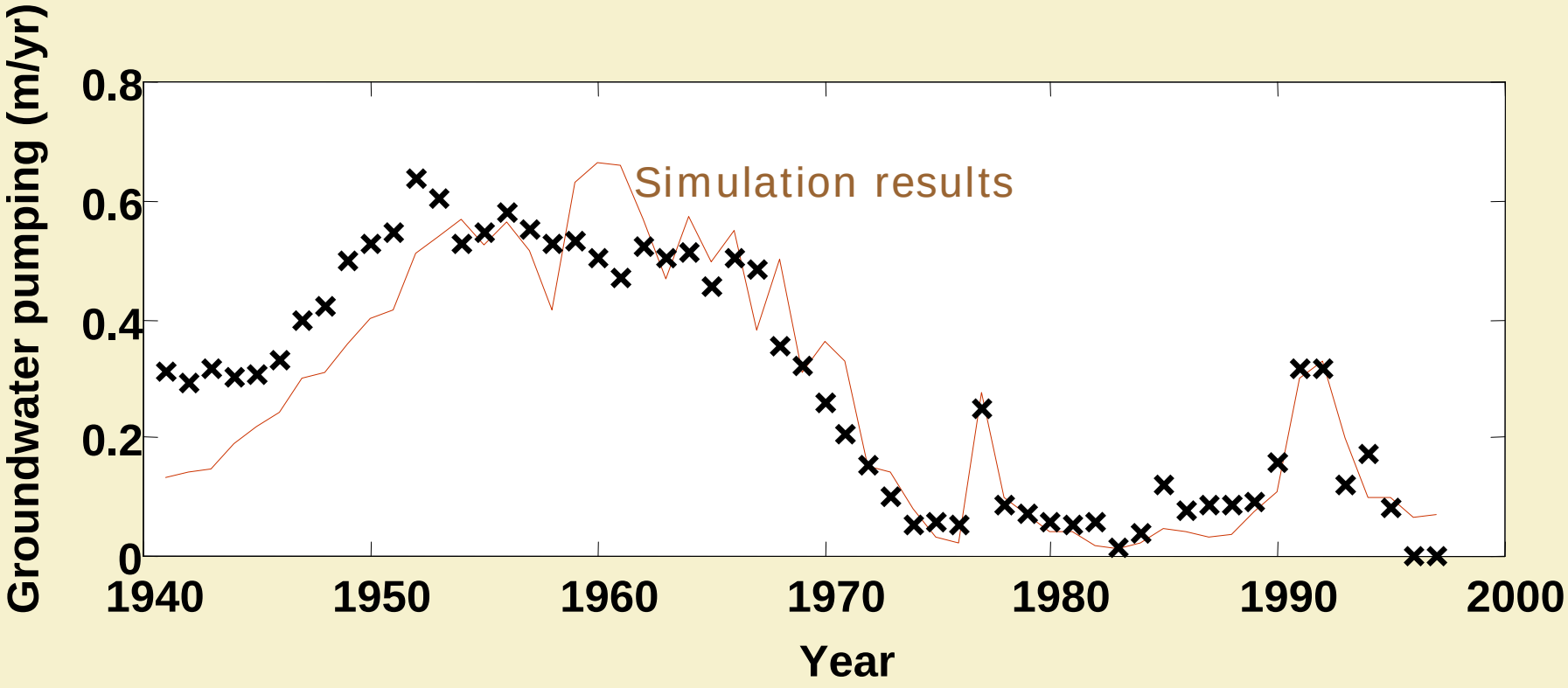
$$\frac{\partial}{\partial x}\left(K_{xx}k_{rw}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}k_{rw}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}k_{rw}\frac{\partial h}{\partial z}\right)-W=n\frac{\partial S_w}{\partial t}+S_wS_s\frac{\partial h}{\partial t}$$

$$S_e=\frac{S_w-S_{wr}}{1-S_{wr}}=\frac{1}{\left[1+\left(\alpha|\psi|\right)^{\beta}\right]^{\gamma}} \qquad for \quad \psi<0$$

$$k_{rw}=S_e^b$$

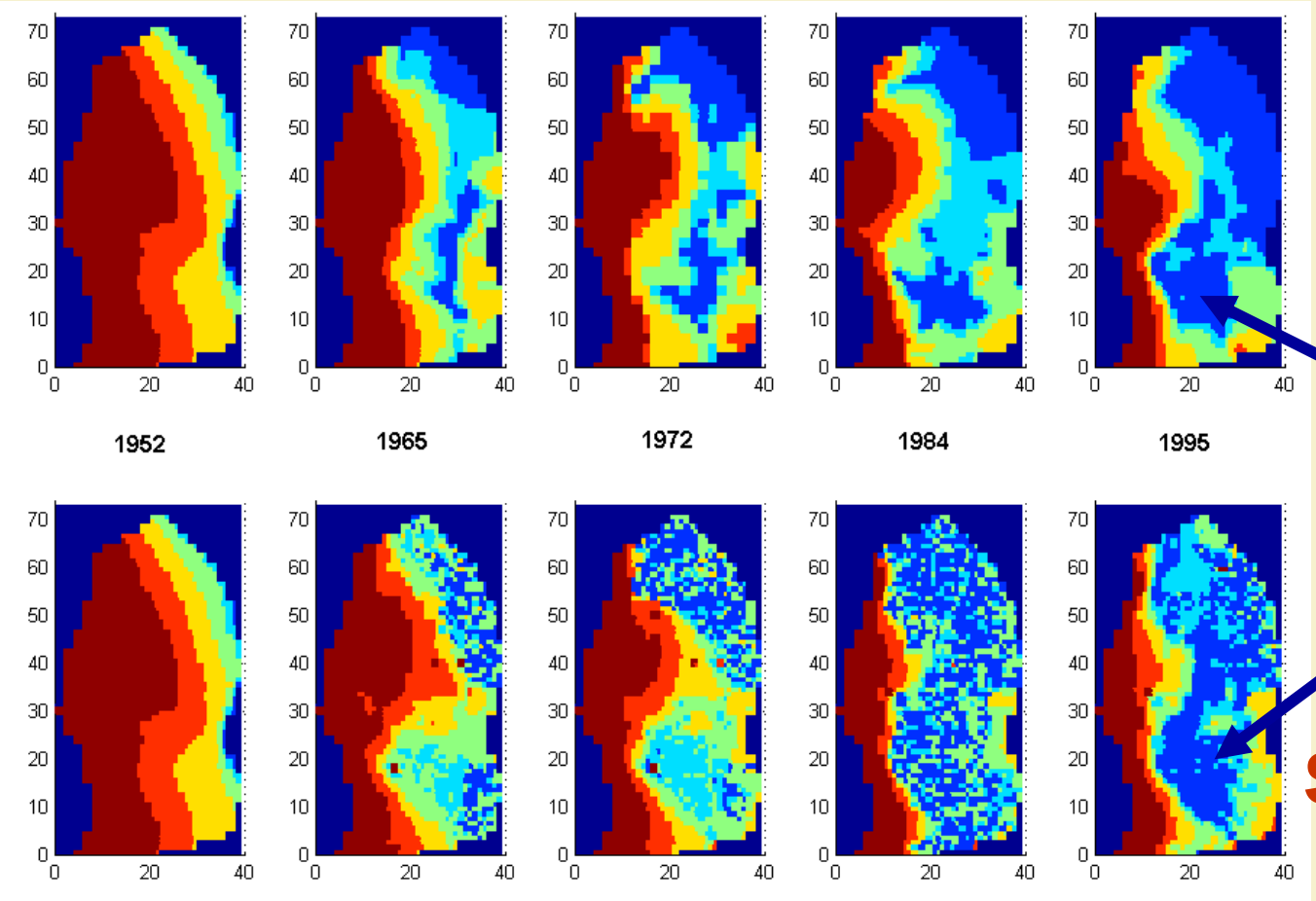
Hydraulic parameters, estimated from neural network analysis, using Rosetta

Comparison of measured with simulated groundwater pumping in Westland's water district



Effect of droughts on groundwater pumping

Reconstruct Ground Water Table from 1950-2000



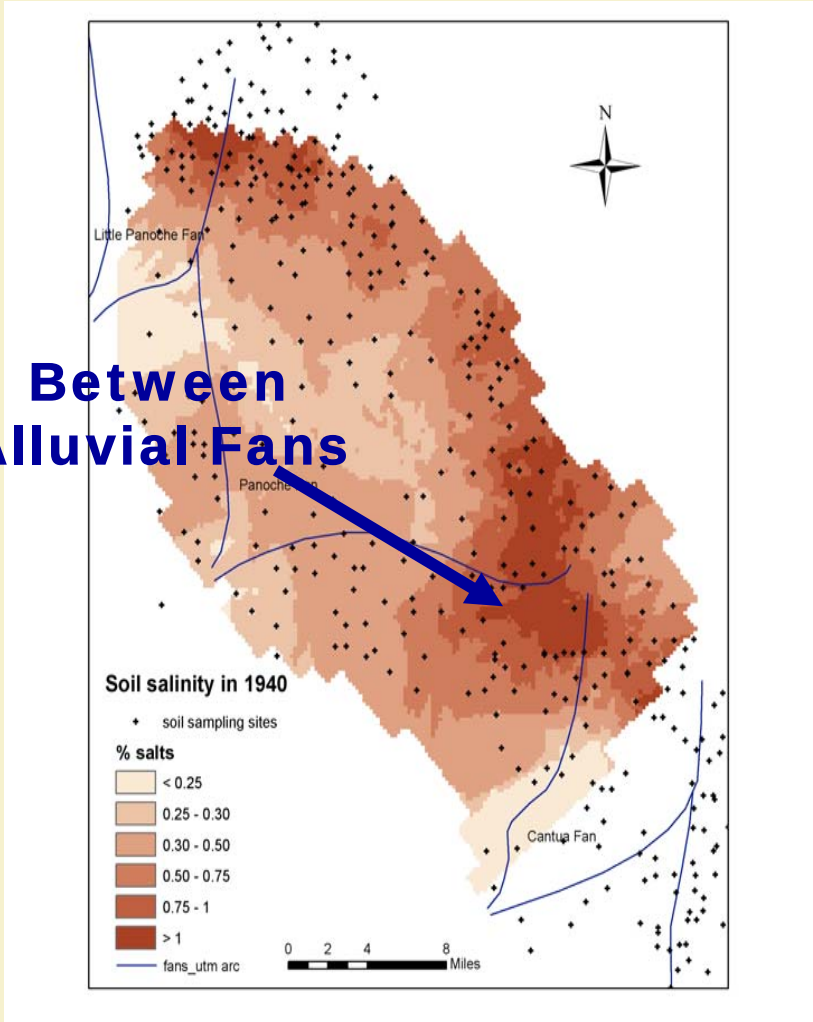
Observed

Inter Fan

Simulated

Comparison of observed and simulated water table depth maps; brown: > 30 m, red: 16-30 m, yellow: 7-16 m, green: 3-7 m, light blue: 2–3 m, blue: < 2 m.

Reconstruct Historical Soil and Groundwater salinity from 1940-2000



Between Alluvial Fans

Pre-development soil salinity

Couple MODHMS with UNSATCHEM

and simulate simultaneous transport of 7 major ions:

Ca, Mg, Na, K, HCO_3, SO_4 and Cl

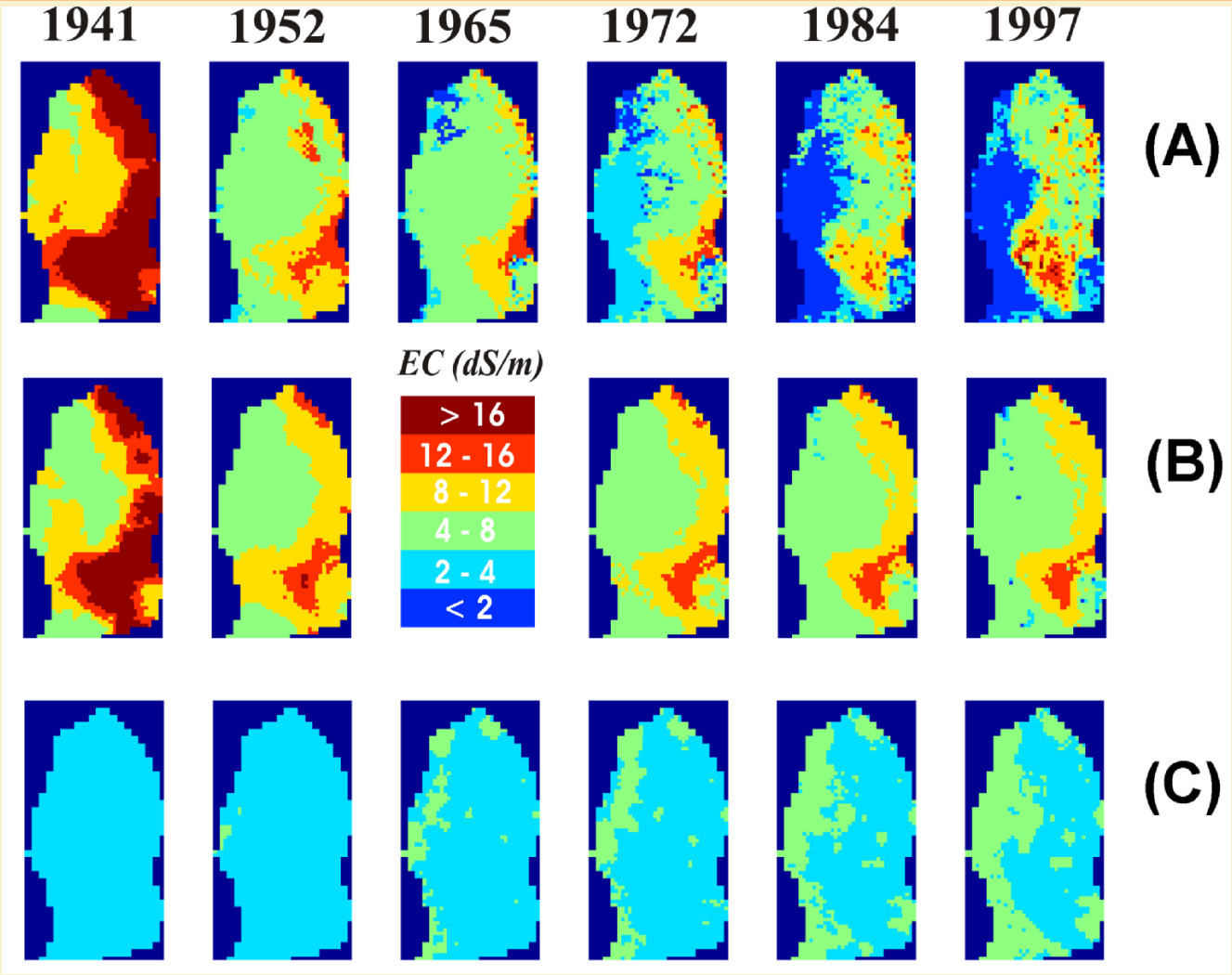
using 3-D CDE

Reconstruct Root zone salinity dynamics

Average root zone

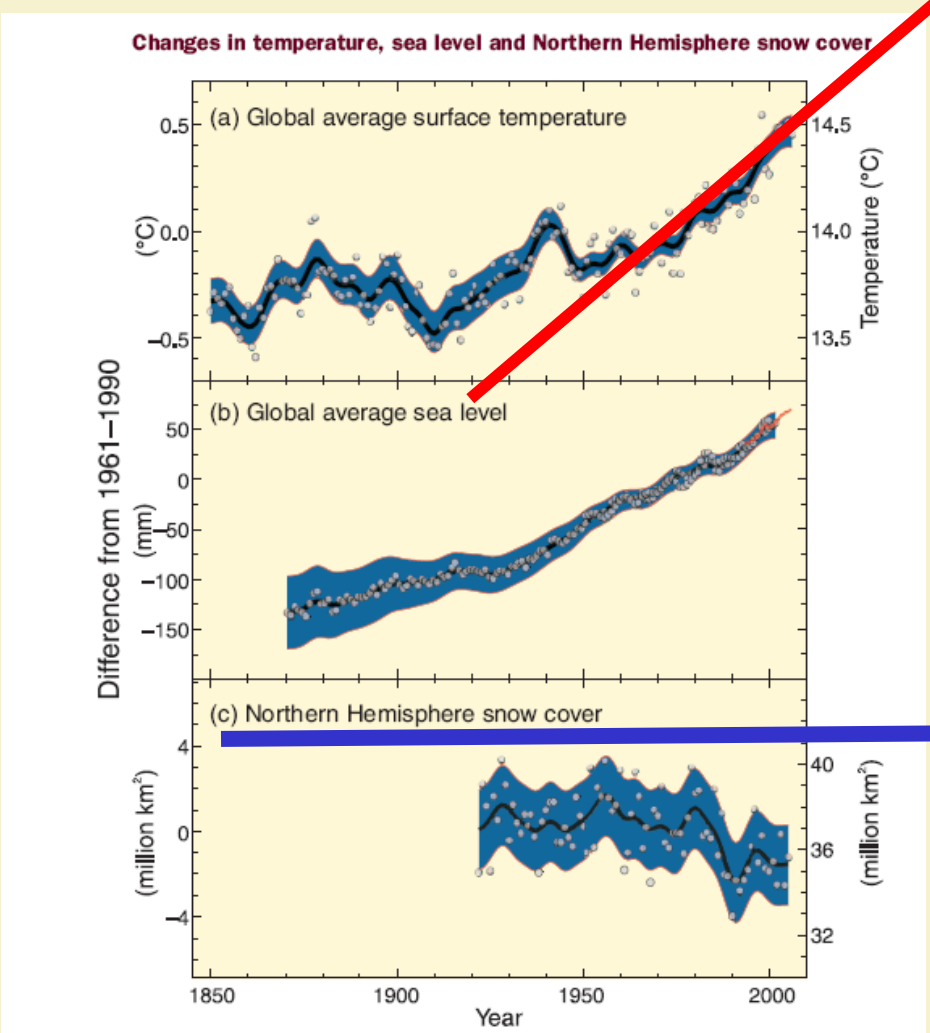
Shallow groundwater (6 m depth)

Deep groundwater (20-60 m)

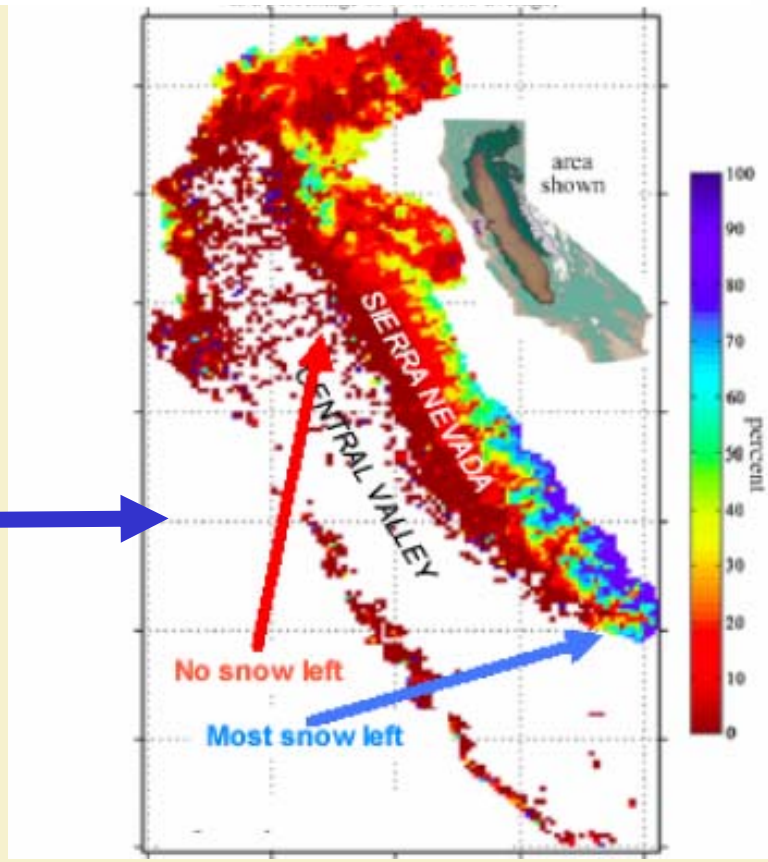


Schoups et al., PNAS, 2005

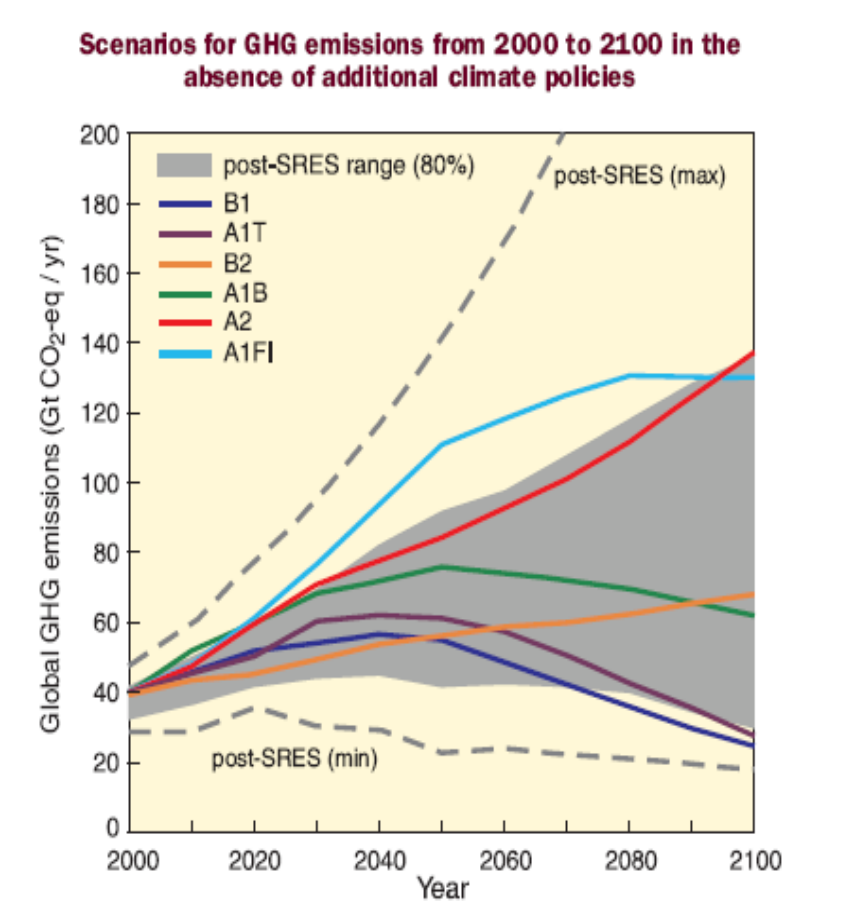
Climate Change 2007: Synthesis Report IPCC (0.2 ºC/decade)



Percent Snow remaining for 2050, as compared to current average snow water equivalent



IPCC Special Report on Emissions Scenarios (SRES, 2000)



A1FI – rapid economic growth, peak population in 2050 and rapid introduction of new technologies, however, fossil intensive.

B1 – same population as A1, but rapid changes in economic structures towards service and information economy.

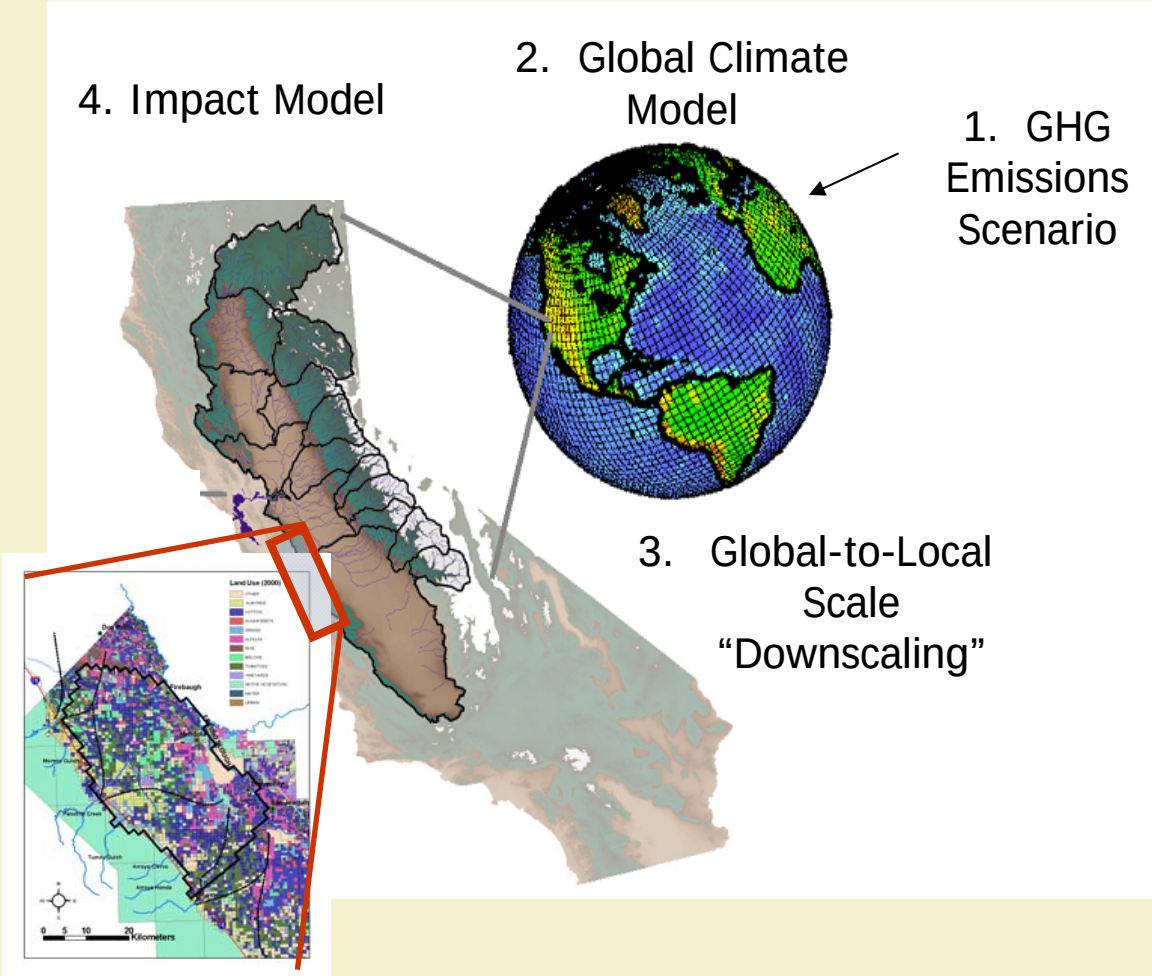
A2 – same population growth, but slow economic development and technological changes.

B1 – highest rainfall and smallest temperature increase

A1FI – lowest rainfall and largest temperature increase

Climate Modeling in SJV –requires downscaling
Statistical Down-scaling

1. Select future atmospheric greenhouse gas scenarios
2. Select GCM's
3. Bias Correct and Downscale GCM Model Output to model domain
4. Forecast ET and precipitation

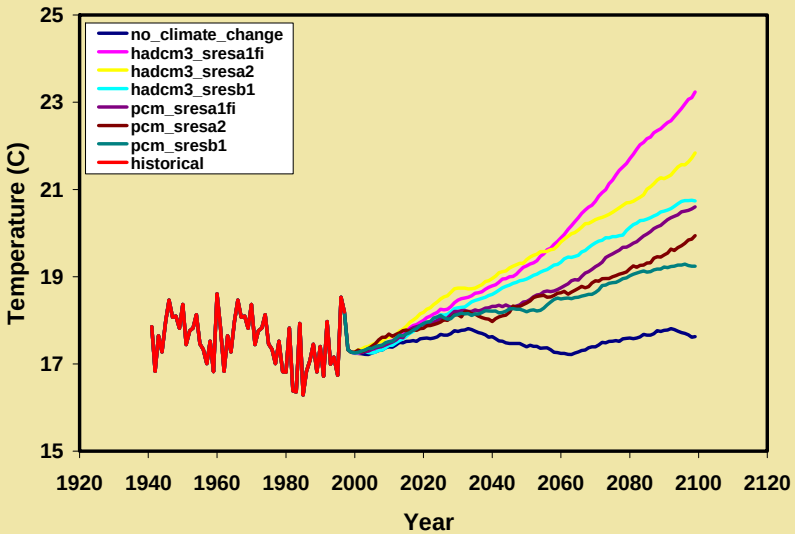


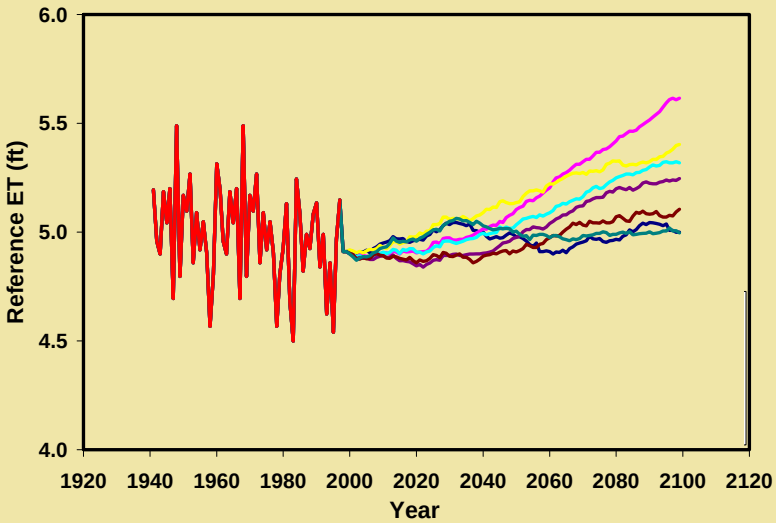
PCM sensitivity is 2.1 ºC

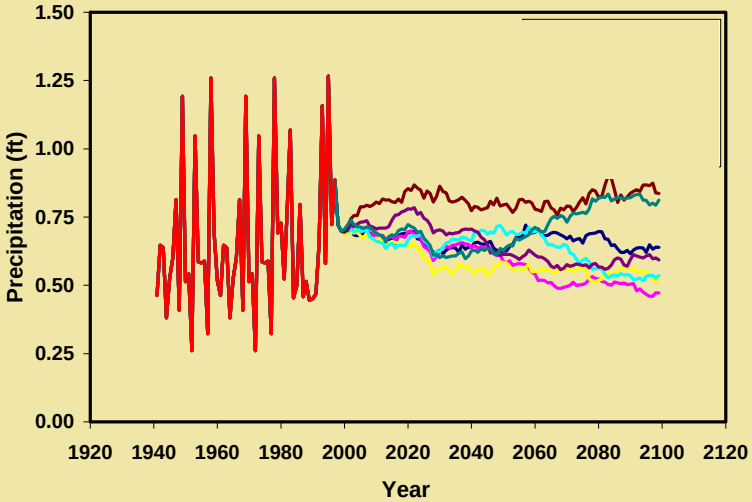
Hadley sensitivity is 3.3 ºC

Figure Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003 by Levi Brekke

Future Temperature, ET_{ref}, and precipitation (30-year moving averages)





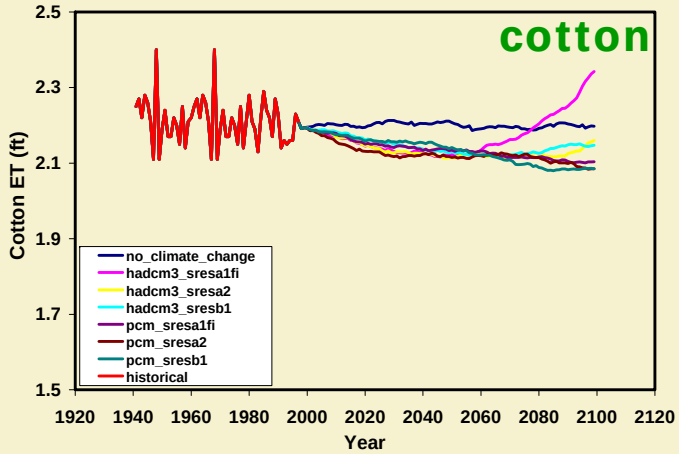


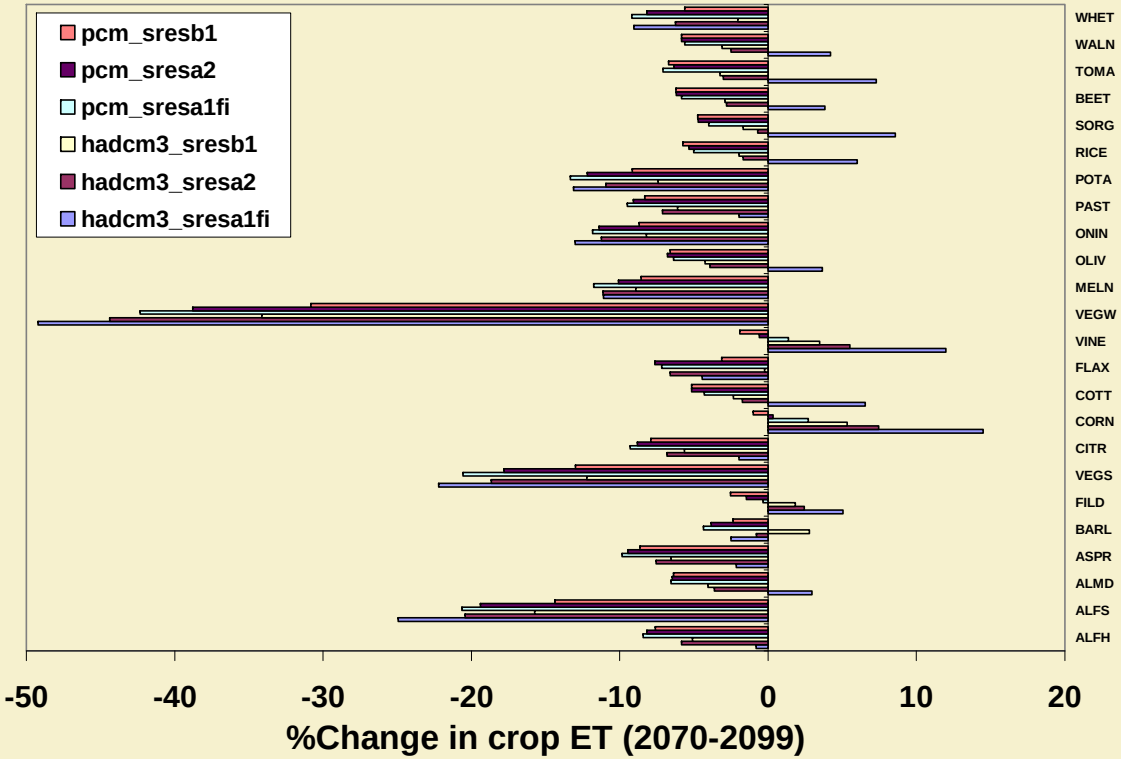
Seasonal crop response to climate change (ET_{crop})
k_c : Crop Coefficient

$$ET_{crop} = Sum[k_c * ET_{ref}]$$

- Effect of increased CO_2 : not so clear, crop-dependent, e.g. C_3 (cotton, tomato, and vegetables) versus C_4 (sorghum, corn)
  - → More biomass production, leaf area and photosynthesis
  - → However, off set by stomata closure
  - → k_c is independent of climate change
- Effect of increased temperature
  - → Faster plant development, shorter growing season
  - → Temperature changes affects ET_{ref}
  - → Possible heat stress for some crops

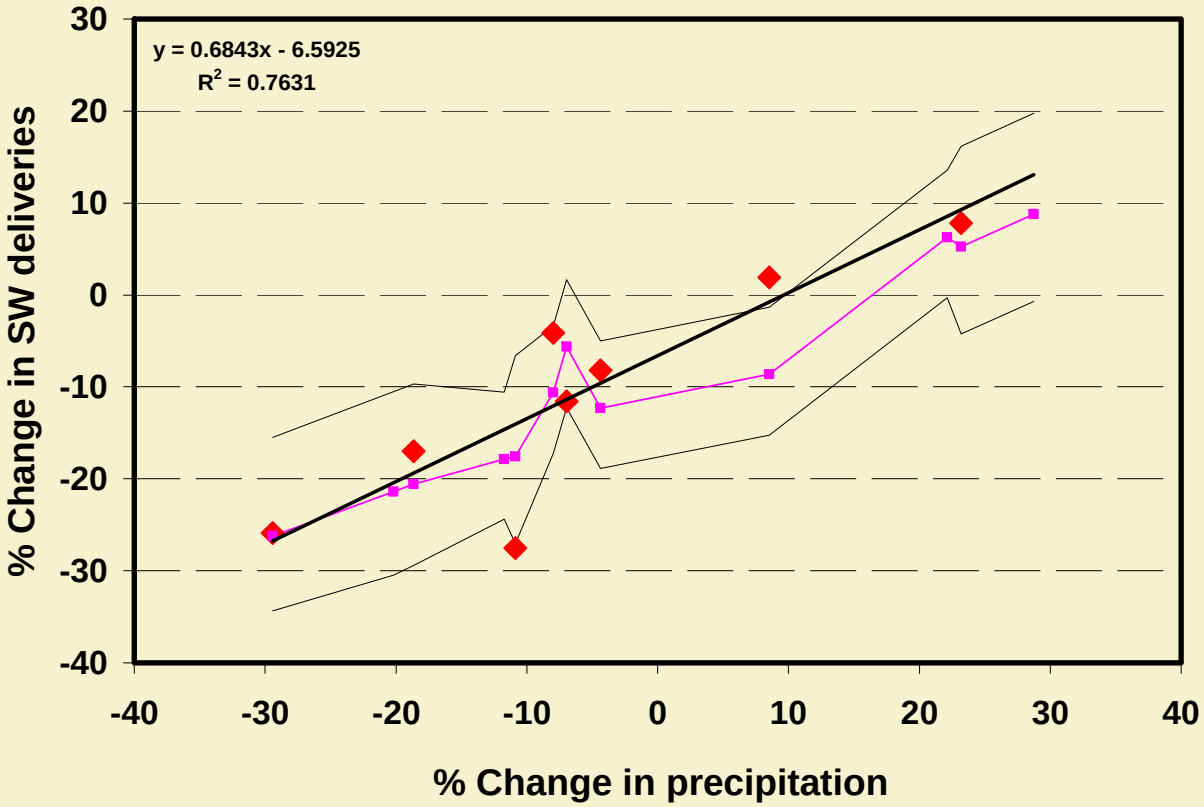
Seasonal ET:
Higher ET_{ref} is offset by shorter growing season





Effect of Climate Change on Surface Water (SW) supply, down-scaled for each water district…..

Correlate precipitation to water supply (sw) from historical data (pink) and from Vicuna et al (2006) model projections (red)



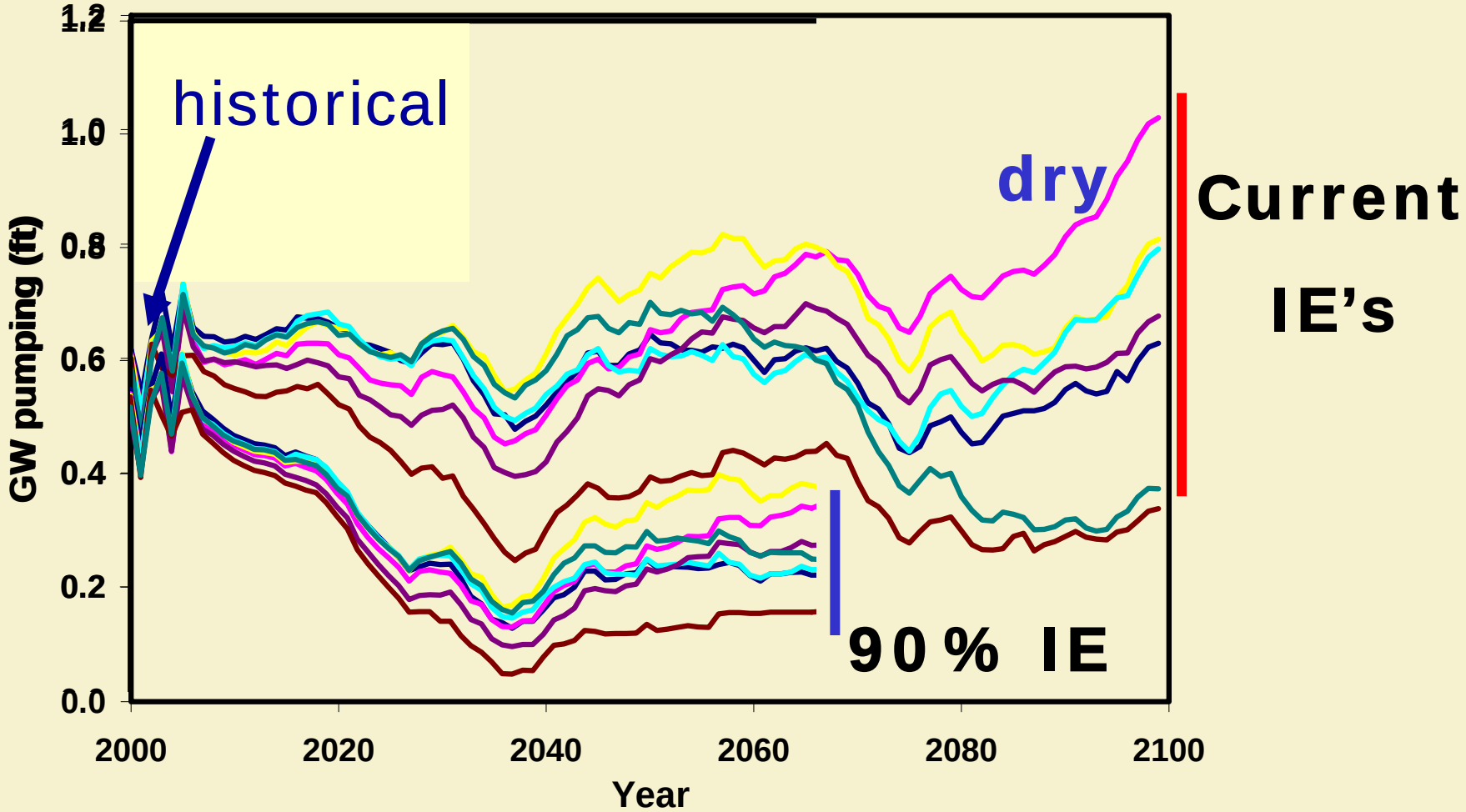
Management Responses: IR = SW + GW
(IR:Irrigation Requirement, SW: Surface- and GW: Ground-Water)

IR = (ET-Precip) / Irr Eff

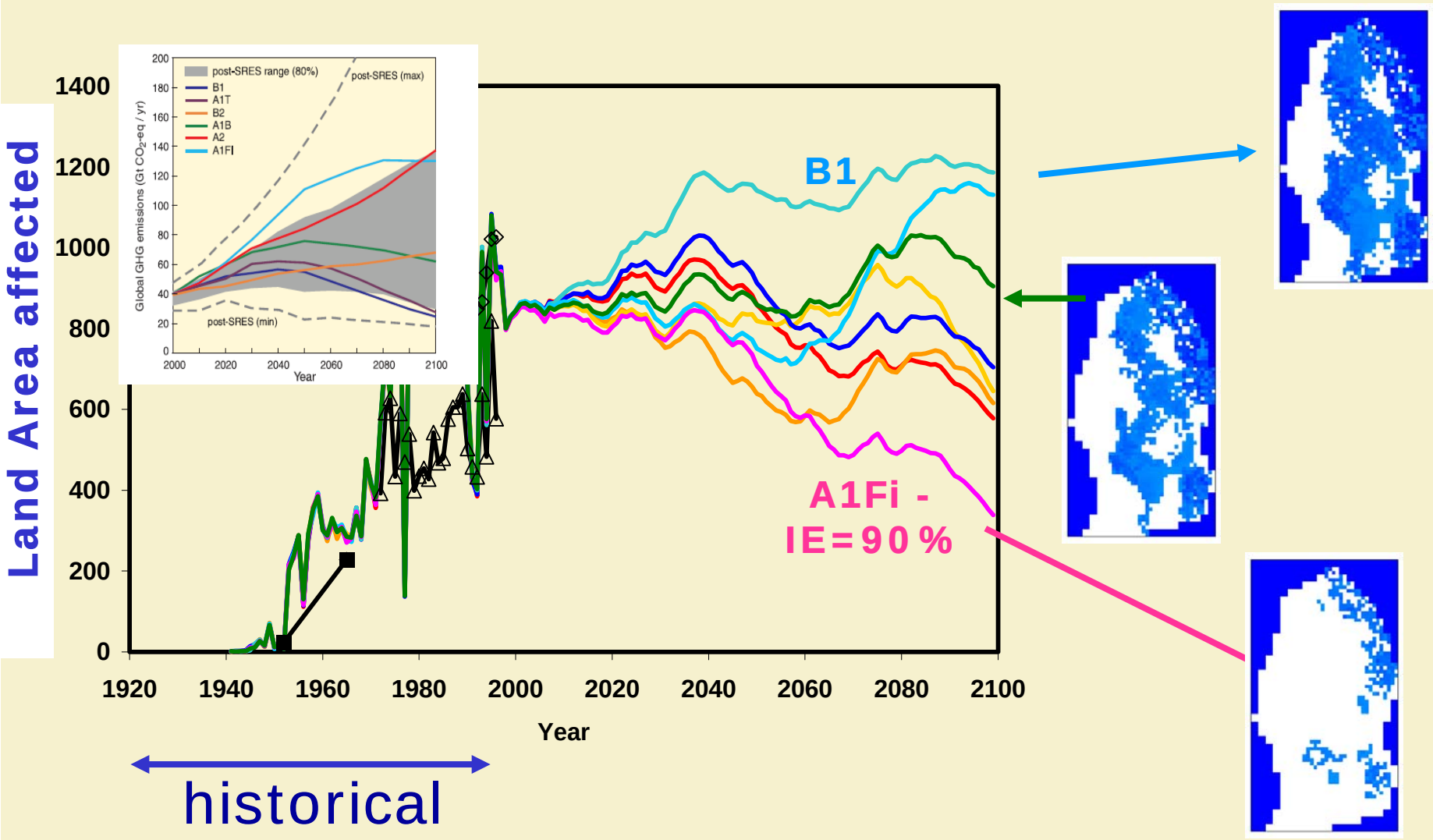
- Increase groundwater pumping, GW:
  - controlled by existing wells,
  - quality of local groundwater, and
  - pumping costs
  - causes irreversible land subsidence
  - affects soil salinity.

- Reduce irrigation requirement, IR:
  - land fallowing and retirement
  - change cropping pattern,
  - develop heat/water resistant cultivars
  - improve irrigation technology/efficiency

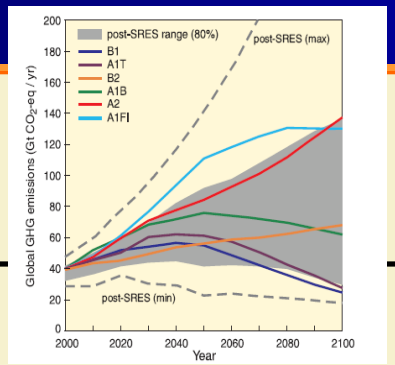
Effect of climate change on groundwater pumping: Compare climate change scenarios with current and 90% irrigation efficiency (IE)

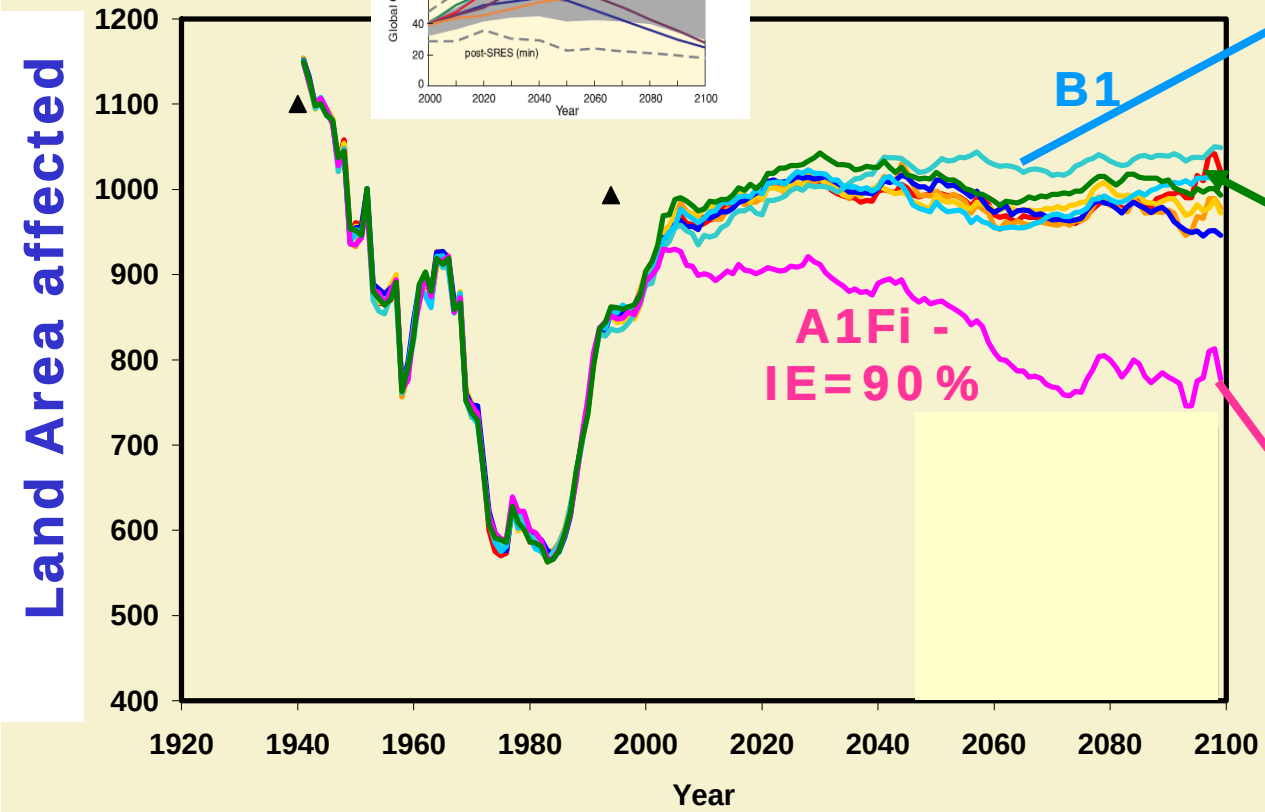


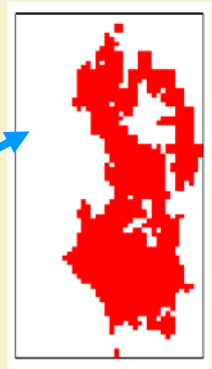
Effect of climate change on shallow groundwater extent:
Compare scenarios with current and 90% irrigation efficiency (IE)

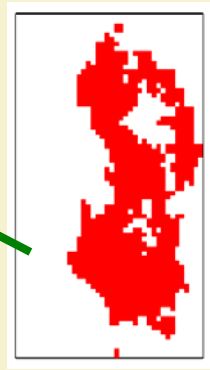


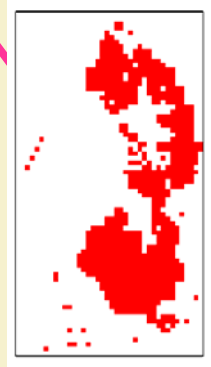
Projection of effect of climate change on soil salinity – Average soil EC > 4 dS/m (top 7 feet)





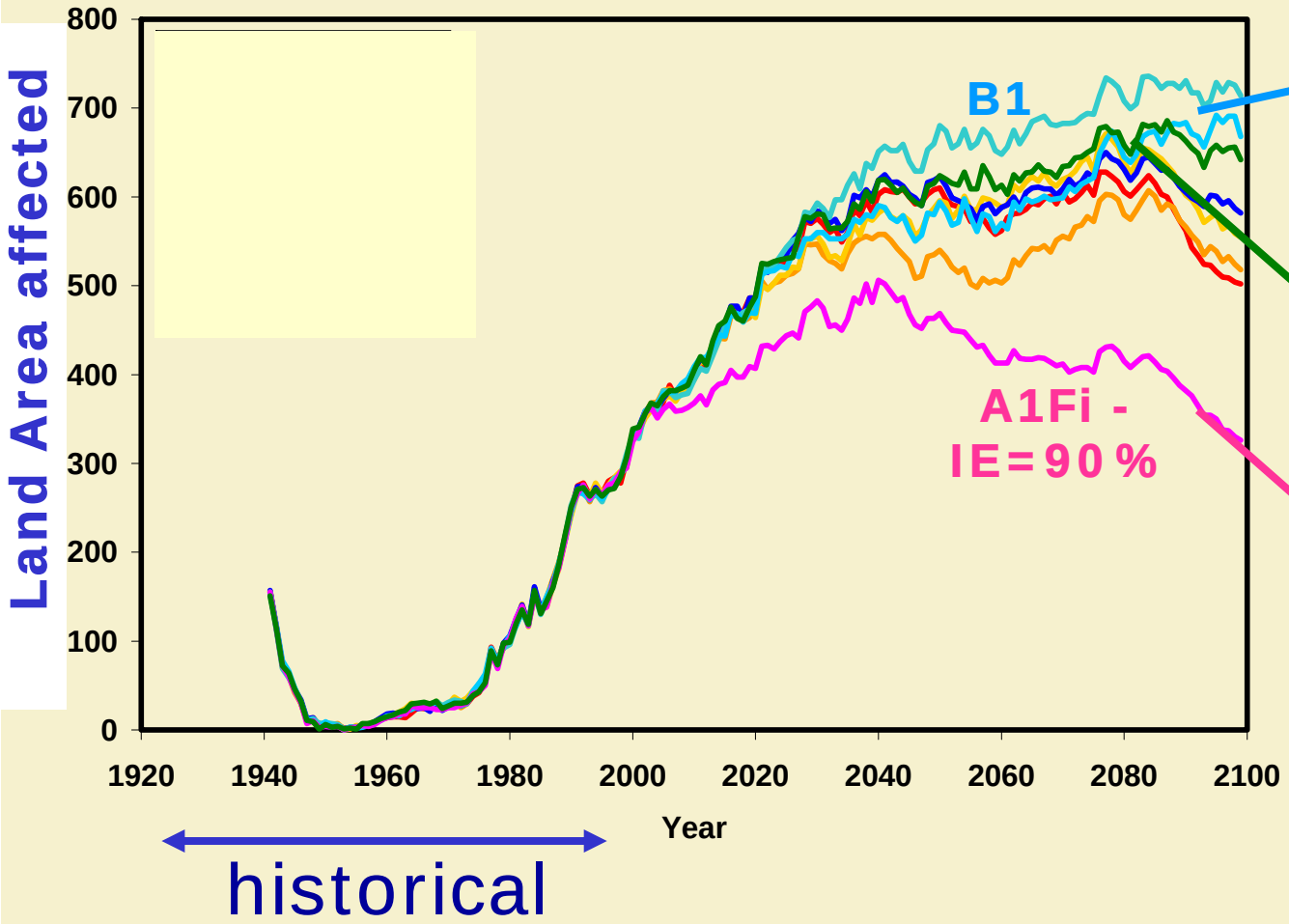


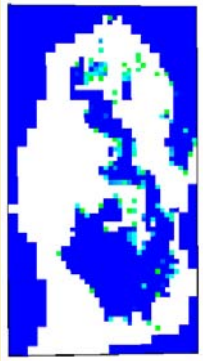


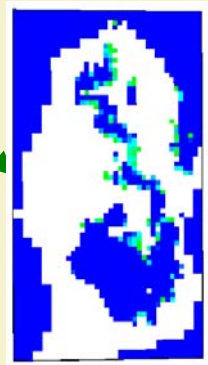


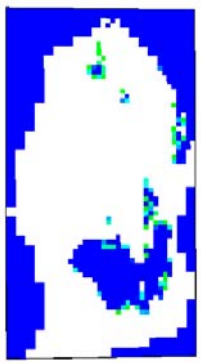
historical

Effect of climate change on tomato yield
(Colored areas depict yield decrease of 50% or more)









Assessment of Climate Warming :

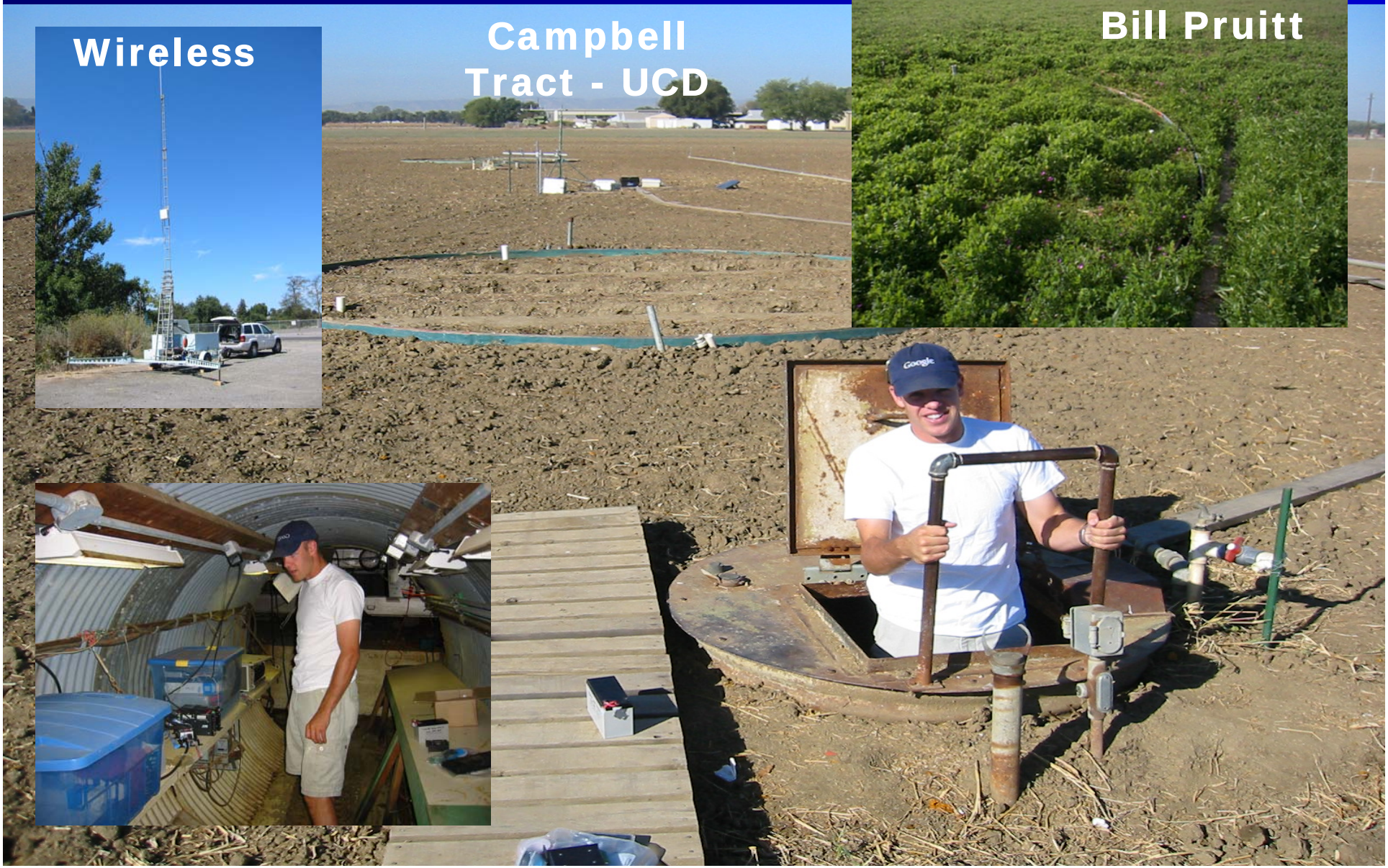
- Annual crop water demand might be reduced by faster crop development;
- Large uncertainty in precipitation and water supply projections;
- Regardless of climate change, soil and groundwater salinity will continue;
- Land subsidence will be very limited;

- Irrigation community will respond by
  - Increasing acreage of land fallowing and retirement
  - Augment crop water requirement by groundwater pumping
  - Improve irrigation efficiency
  - Shift to high-value and salt-tolerant crops

Climate change impacts on water demand and salinity in California's irrigated agriculture. 2008. G. Schoups, E.P. Maurer, and J.W. Hopmans. Climatic Change.

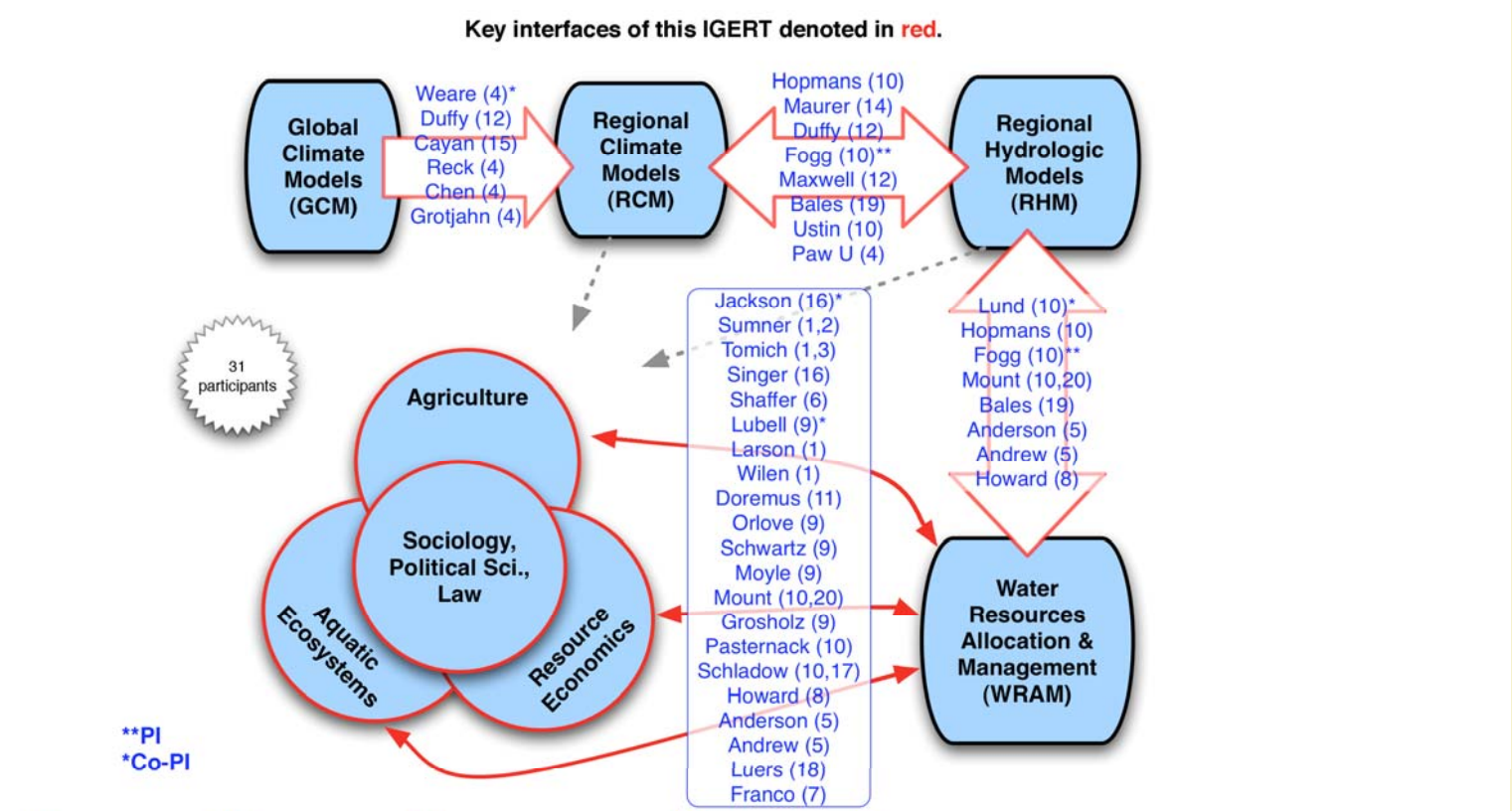
Additional work is required on quantifying uncertainties in projected climate change predictions and impacts

Proposed UCD-DWR Lysimeter study

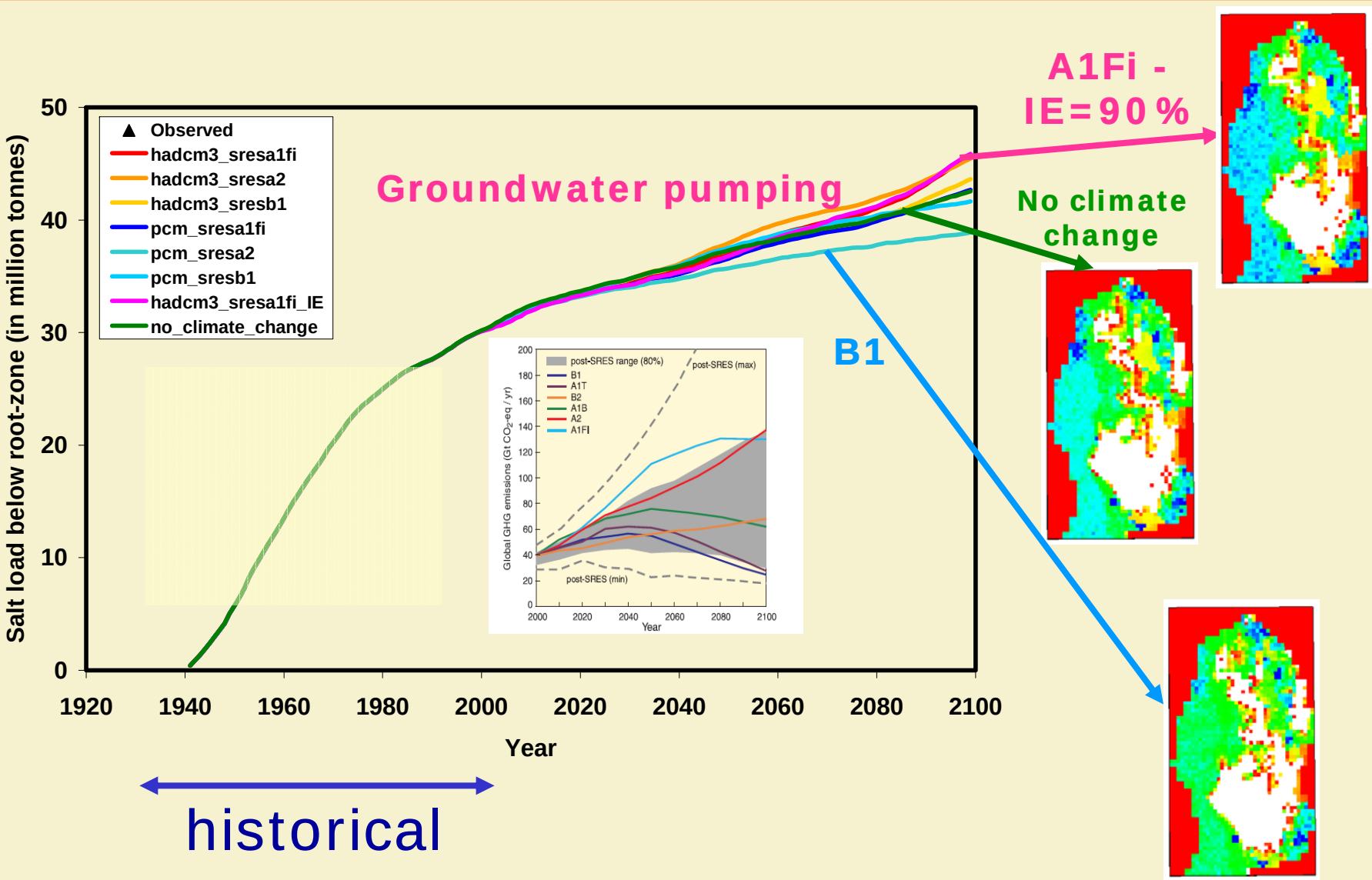


UCD IGERT Proposal: Climate Change Effects on Water Resources, Aquatic Ecosystems, and Agriculture (CCEWAA)

The goal of this IGERT is to train graduate students that are both deeply competent in one or more specific disciplines and broadly conversant in the multiple disciplines that determine the ultimate effects of climate change on society and the natural world.



Questions & Comments

Effect of climate change on salt load (dissolved) to groundwater: Cumulative salt load, Million Tons of salt

Blue-green-yellow-red (high to low)