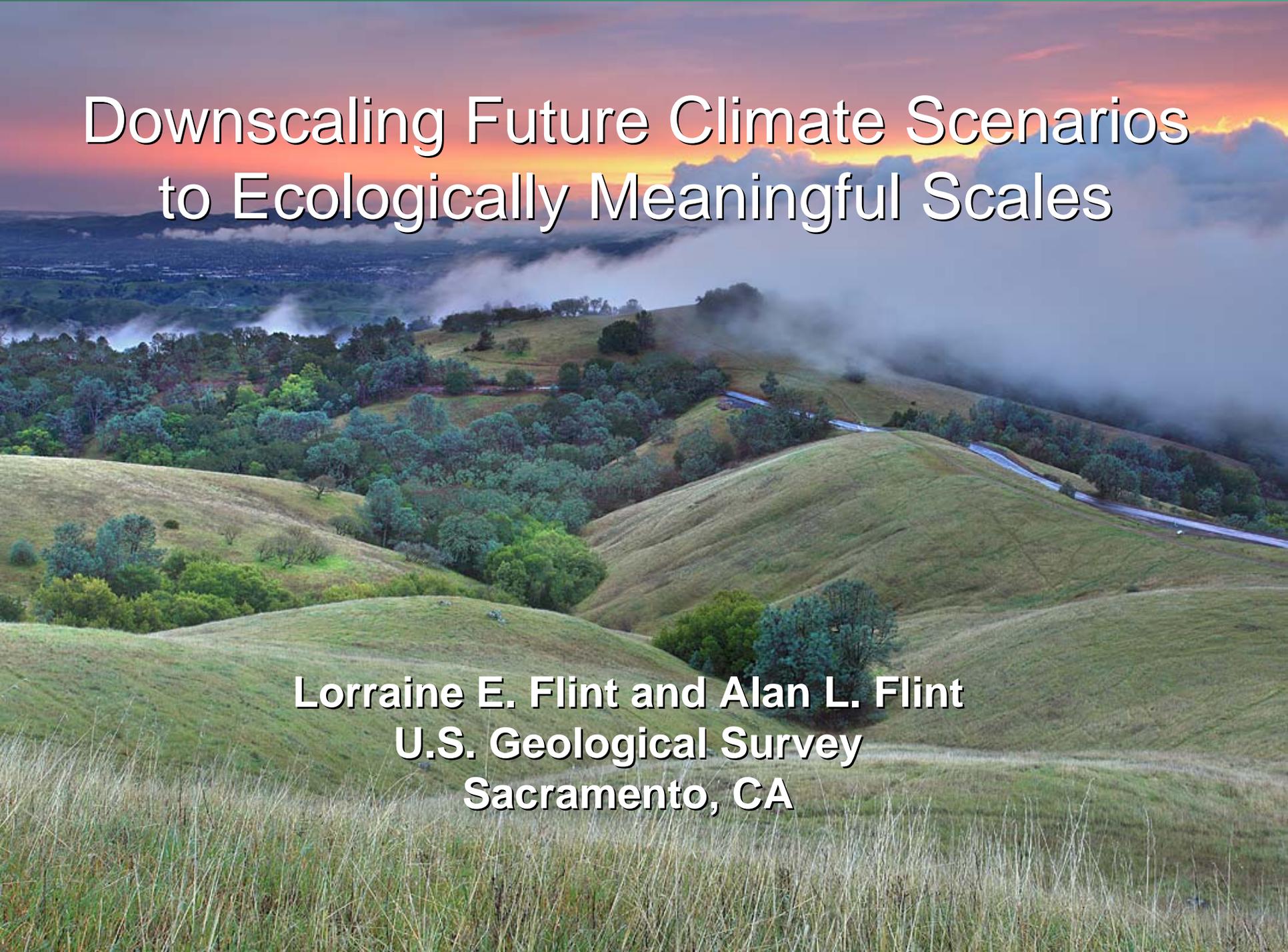


# Downscaling Future Climate Scenarios to Ecologically Meaningful Scales



**Lorraine E. Flint and Alan L. Flint**  
**U.S. Geological Survey**  
**Sacramento, CA**

# Introduction

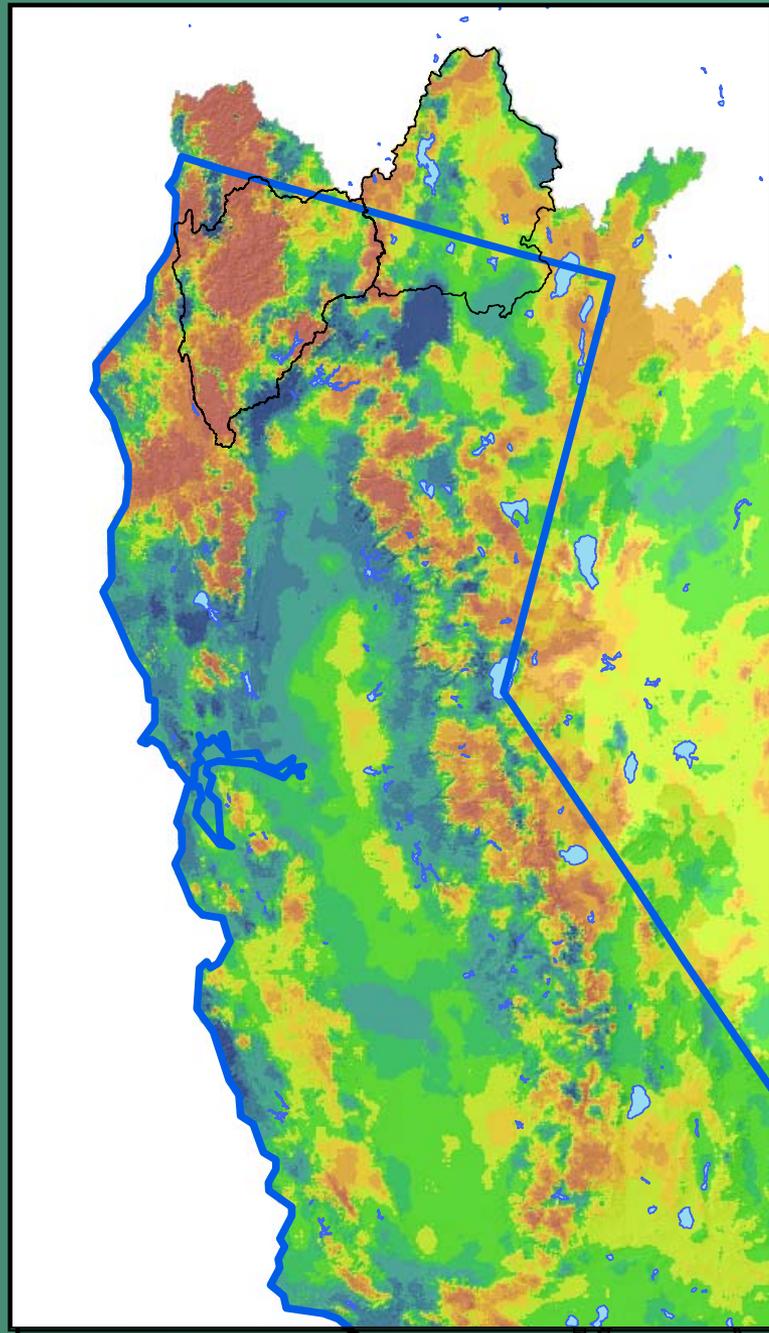
- Evaluating impacts of climate change on water resources and ecologic processes on the landscape is an integral part of land and resource management
- Spatial scale of climate projections is one of the largest constraints to environmental investigations
- Translation of climate projections into hydrologic response at a fine scale is necessary for understanding processes at the scale at which they occur



# Change in Precipitation

1970-2007

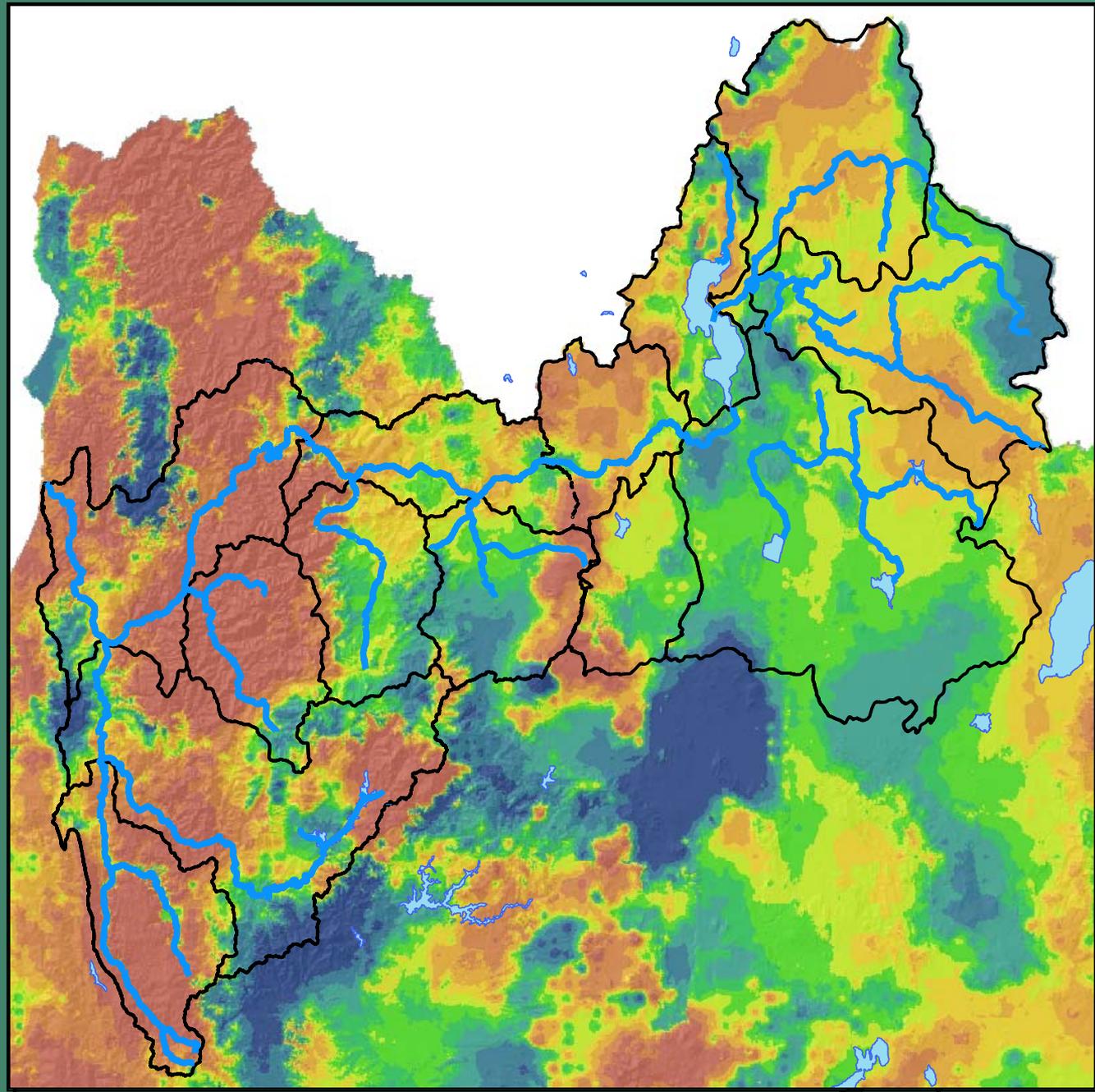
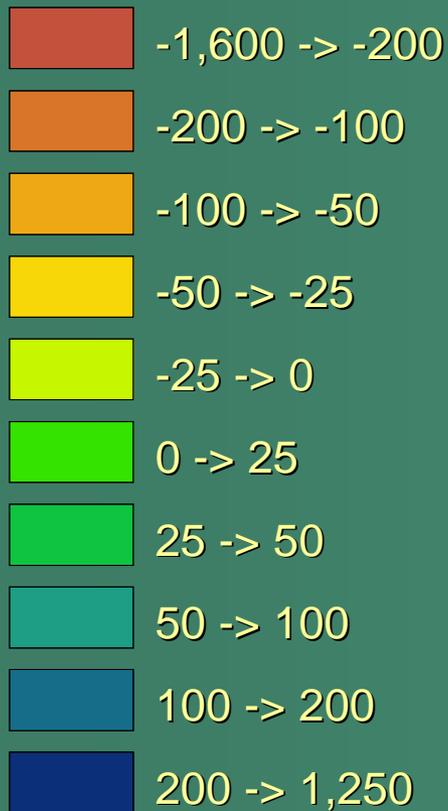
(mm/year)



# Change in Precipitation

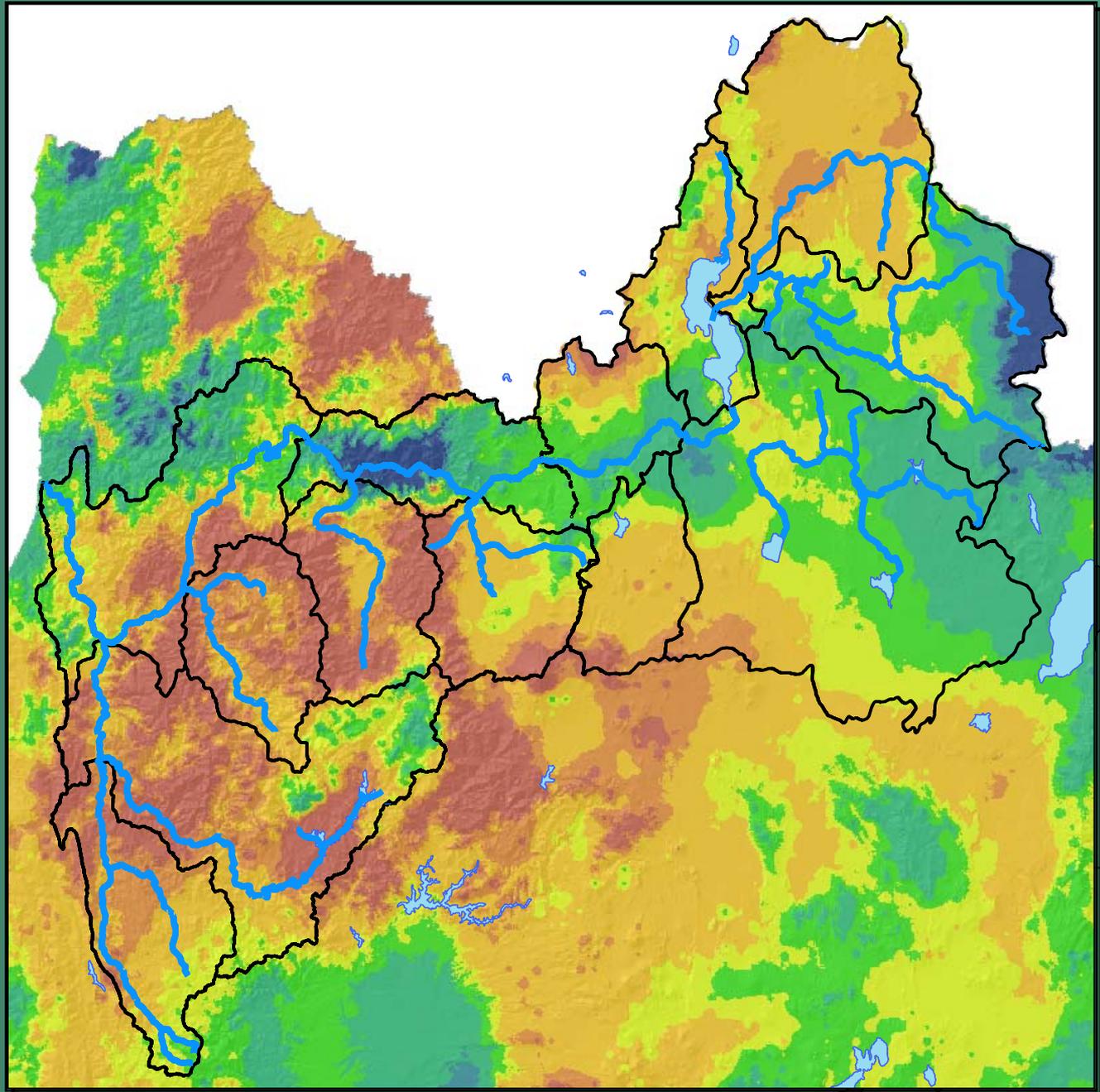
1970-2007

(mm/year)



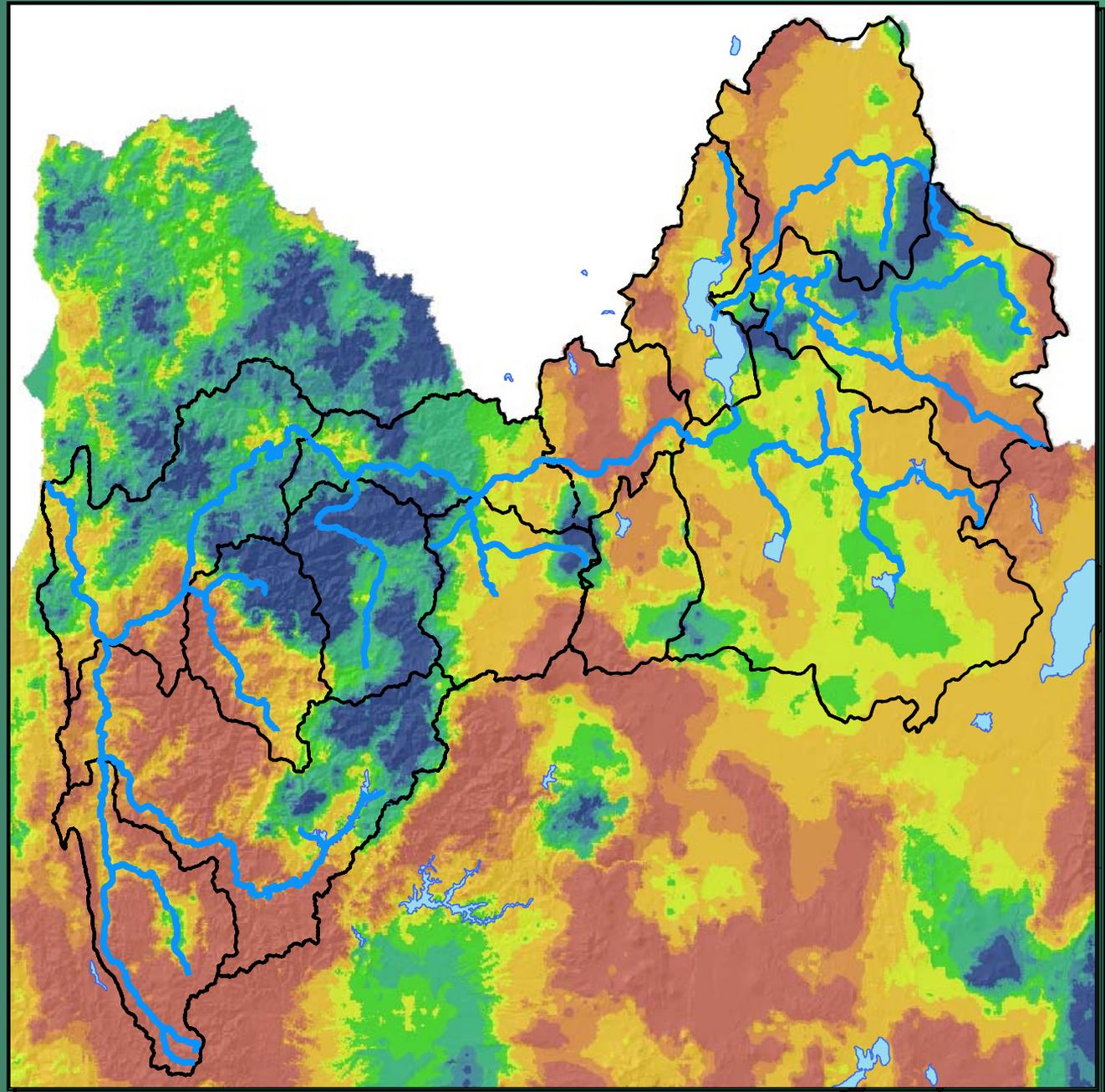
# Change in Minimum Air Temperature

1970-2007  
(mm/year)

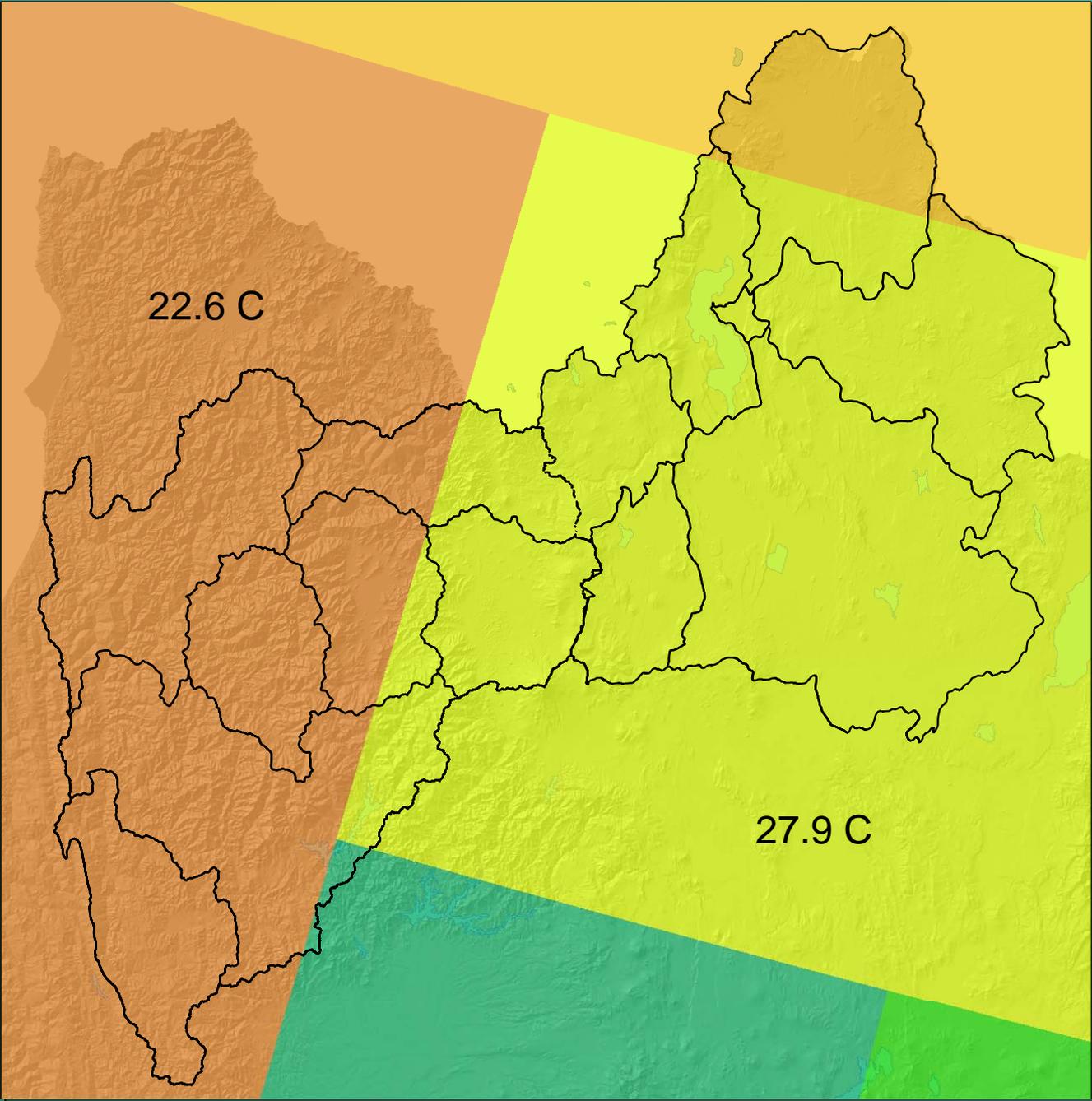


# Change in Maximum Air Temperature

1970-2007  
(mm/year)



# 2-deg grid

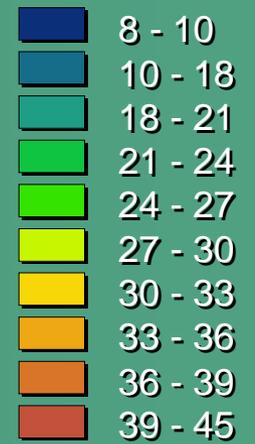
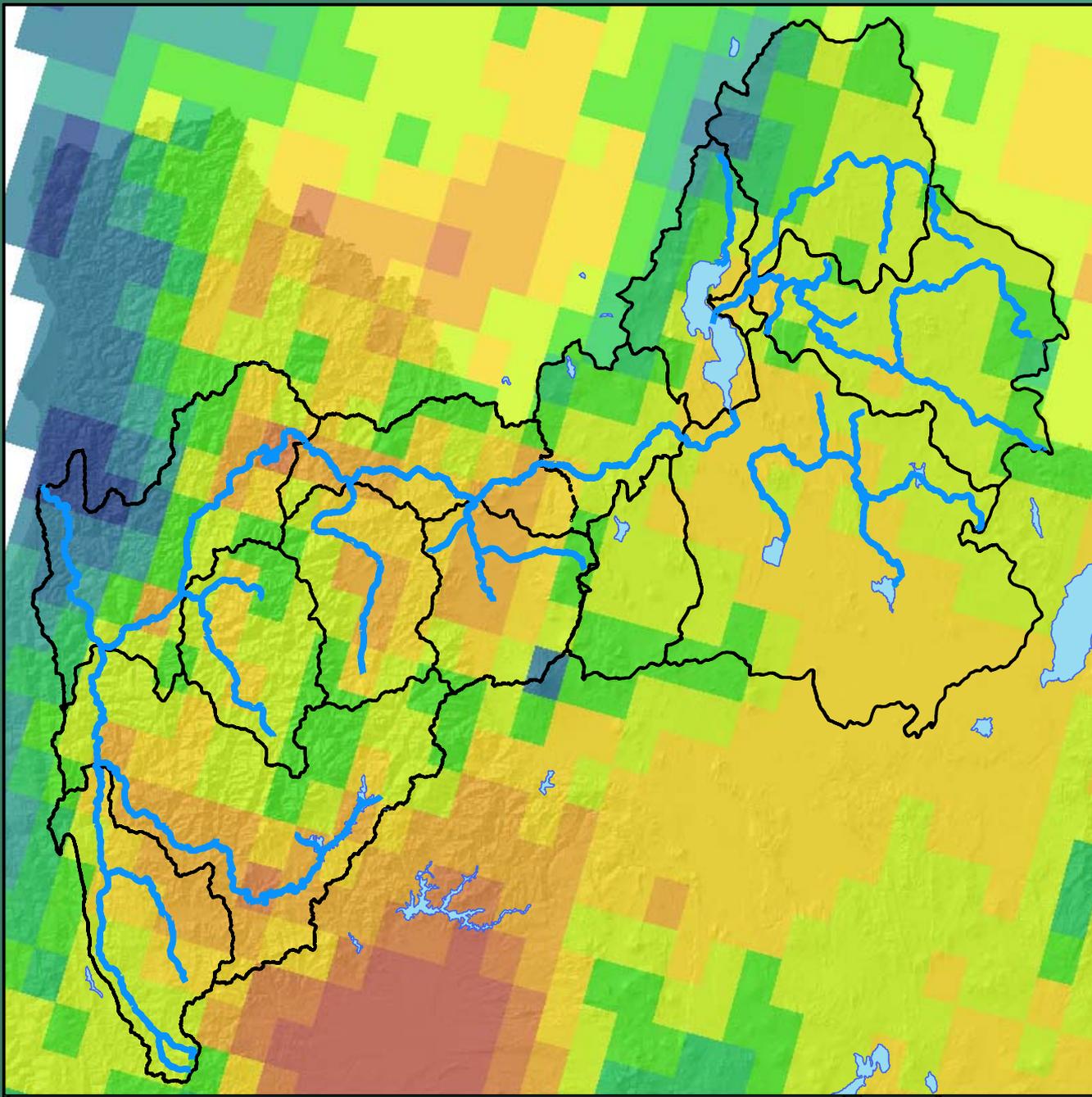


Maximum  
Air  
Temperature  
June 2035  
(degrees C)

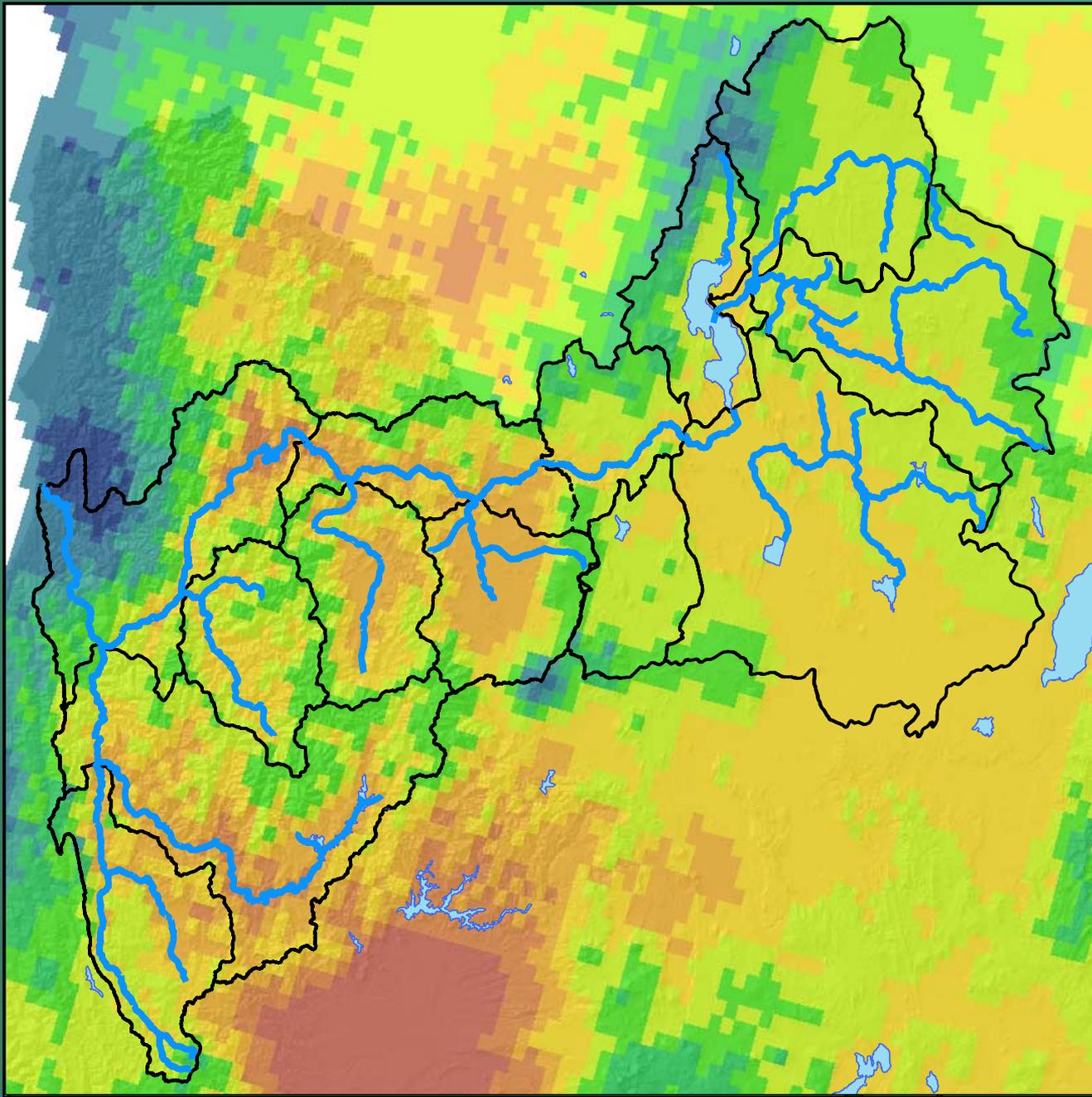
- 8 - 10
- 10 - 18
- 18 - 21
- 21 - 24
- 24 - 27
- 27 - 30
- 30 - 33
- 33 - 36
- 36 - 39
- 39 - 45

# 12-km grid

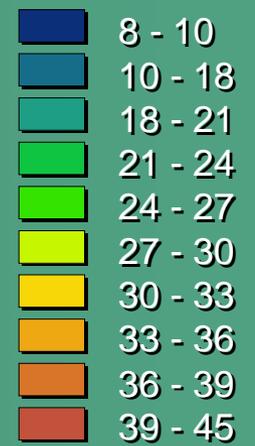
Maximum  
Air  
Temperature  
June 2035  
(degrees C)



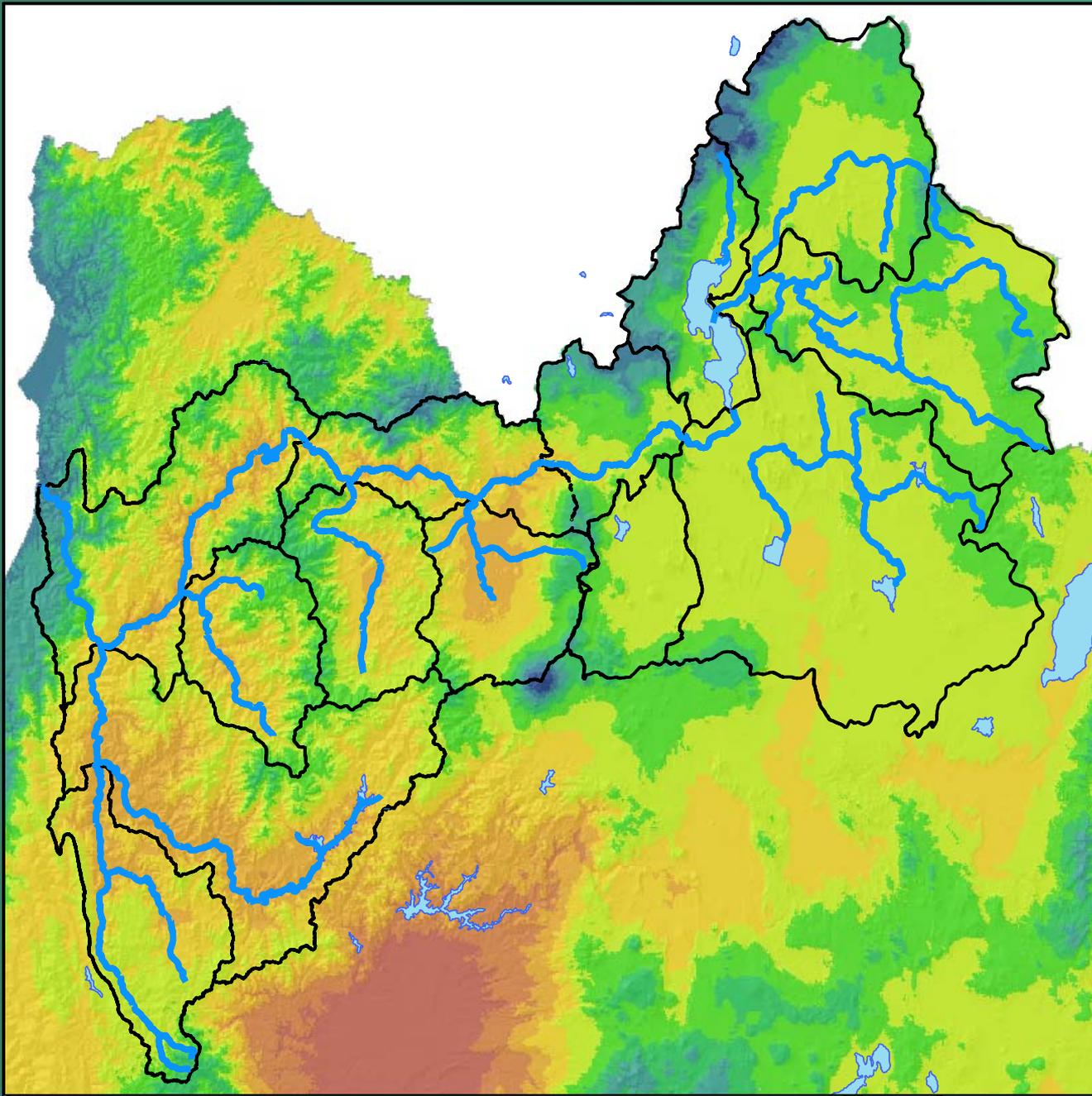
# 4-km grid



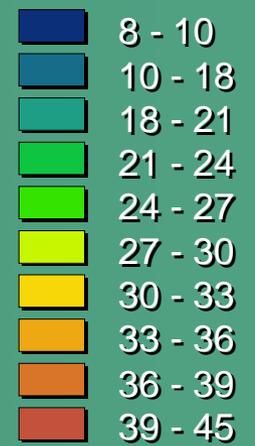
Maximum  
Air  
Temperature  
June 2035  
(degrees C)



# 270-m grid

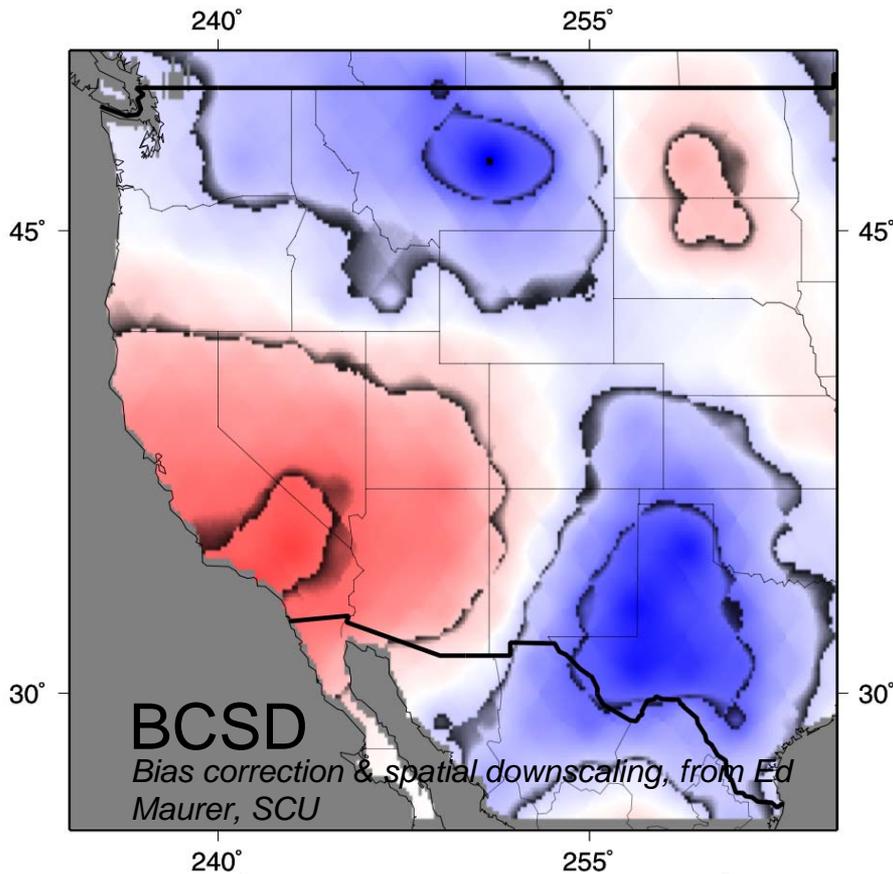


Maximum  
Air  
Temperature  
June 2035  
(degrees C)

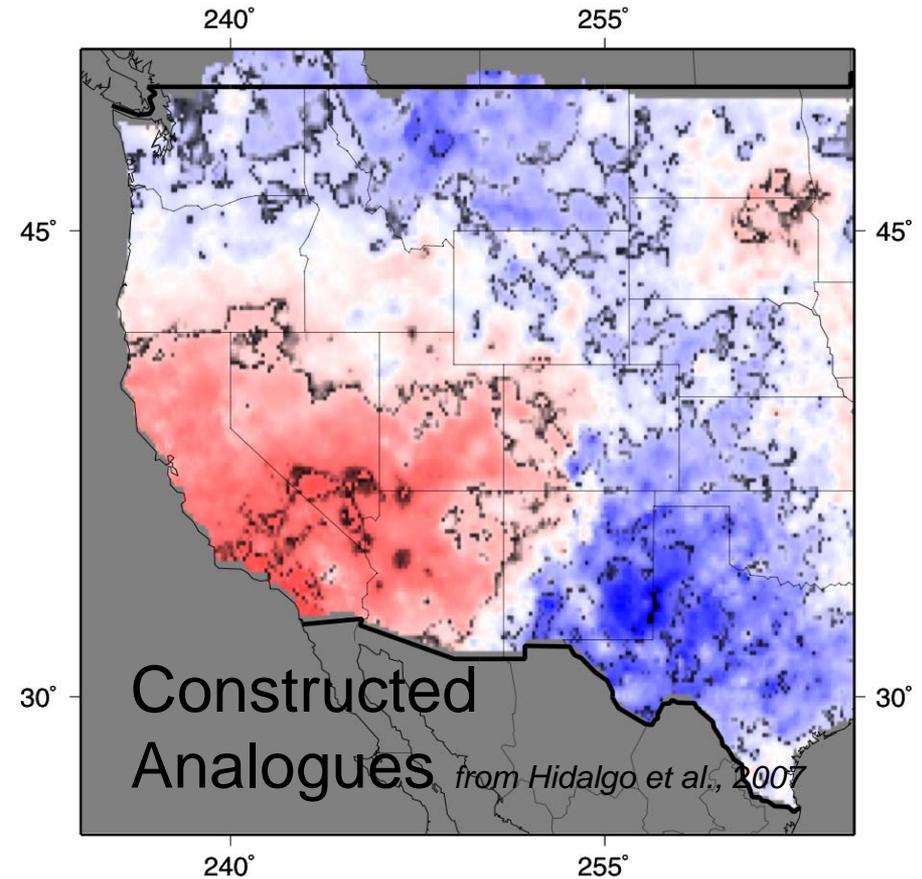


# Downscaled Projected Trends in December Precipitation by Two Approaches (GFDL CM2.1, A2 emissions, 21st Century)

2000-2098 TRENDS  
IN PRECIPITATION (BCSD)

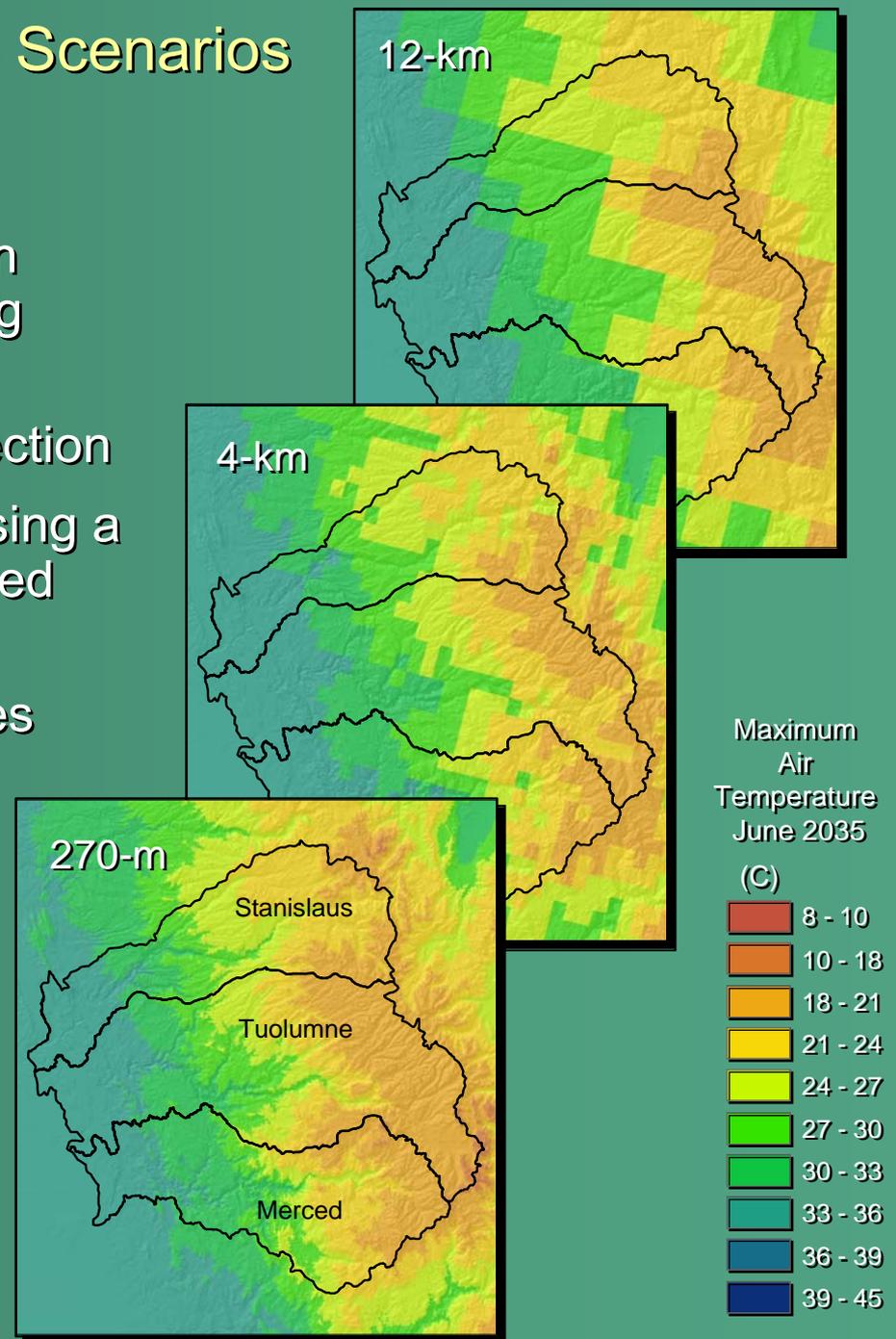


2000-2098 TRENDS  
IN PRECIPITATION (CA)



# Processing of Climate Change Scenarios

- Statistical Downscaling
  - GCM data at ~275-km resolution were downscaled to 12-km using constructed analogues
- Spatial Downscaling and Bias Correction
  - Spatially downscaled to 4-km using a gradient-inverse-distance-squared (GIDS) method
  - Statistical transformation ensures that the climate model and historical data have similar statistical properties: the mean and standard deviation of the 1950-2000 period were used for corrections
- Data is further downscaled to 270-m using GIDS for model application



# Gradient Inverse Distance Squared (GIDS) approach to fine resolution downscaling

For every month, for every grid cell, an equation is developed to downscale from 12-km to 4-km on the basis of:

$$Z = \left[ \frac{\sum_{i=1}^N \frac{Z_i + (X - X_i) \times C_x + (Y - Y_i) \times C_y + (E - E_i) \times C_e}{d_i^2}}{\sum_{i=1}^N \frac{1}{d_i^2}} \right]$$

(Nalder and Wein, 1998)

Z = climate variable of interest, precipitation or air temperature at 4-km grid cell

Z<sub>i</sub> = climate variable at 12-km grid cell i

X = easting

Y = northing

E = elevation

N = number of 12-km grid cells in the specified search radius

d<sub>i</sub> = distance from 4-km site to 12-km cell (no less than 12-km, provides nugget)

C<sub>x</sub>, C<sub>y</sub>, C<sub>e</sub> = regression coefficients for easting, northing, and elevation

Search radius of 27 km limits influence of distant data, allows for ~ 21 12-km cells to estimate each 4-km cell, weighted to the closest cell

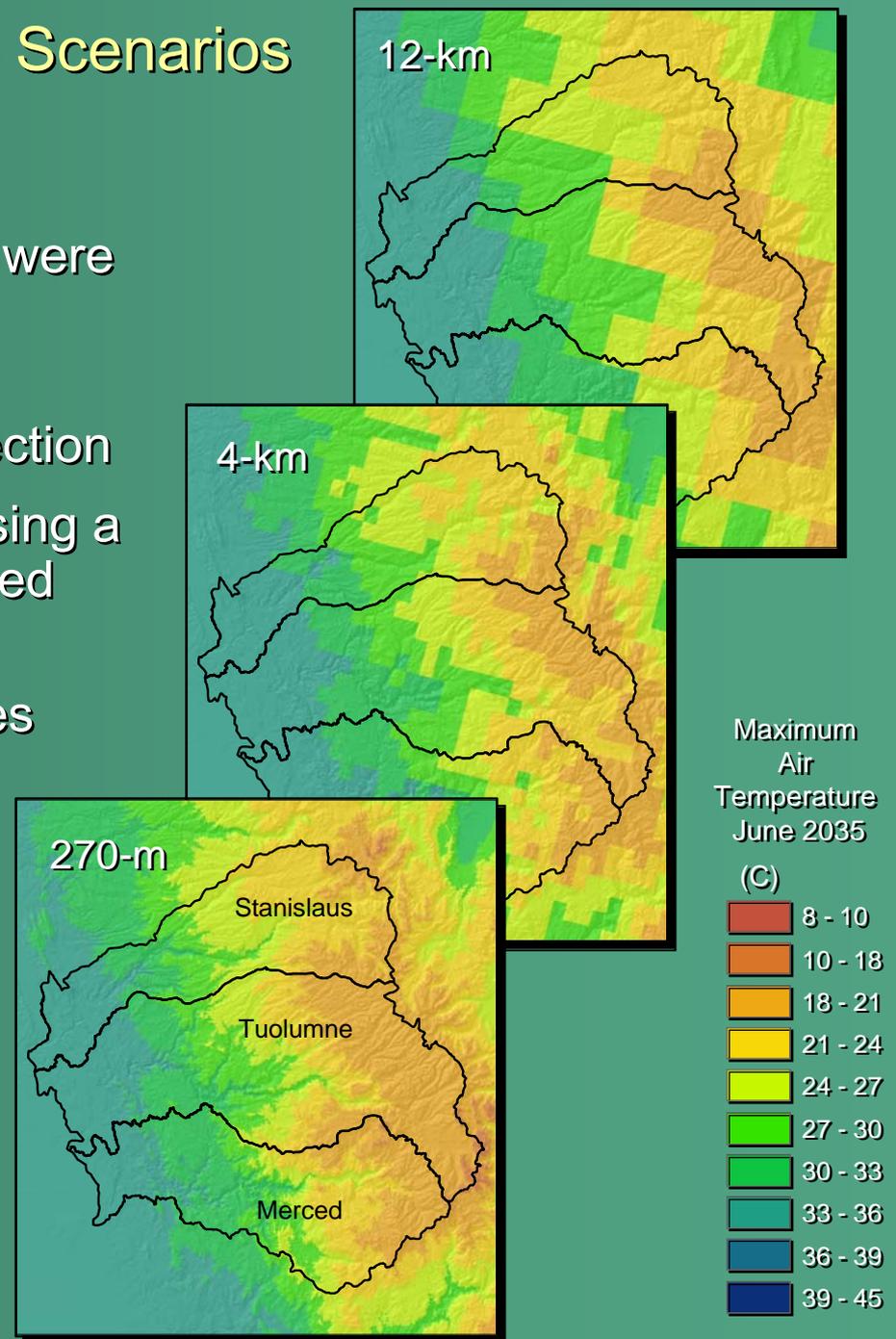
# Bias Correction

- Climate model data represents trends or changes, not absolute values
- Statistical transformation is necessary to ensure that the climate model and historical data have similar statistical properties
- Measured baseline period, 1950-2000, is used for correction of climate data
- Various approaches include
  - Quantile mapping and adjustment of CDFs
  - Statistical scaling
    - annual averages or monthly averages: absolute difference for temperature, ratio for precipitation
    - monthly averages spatially explicit, using a correction factor for each grid cell and mean and standard deviation of the baseline period used for correction

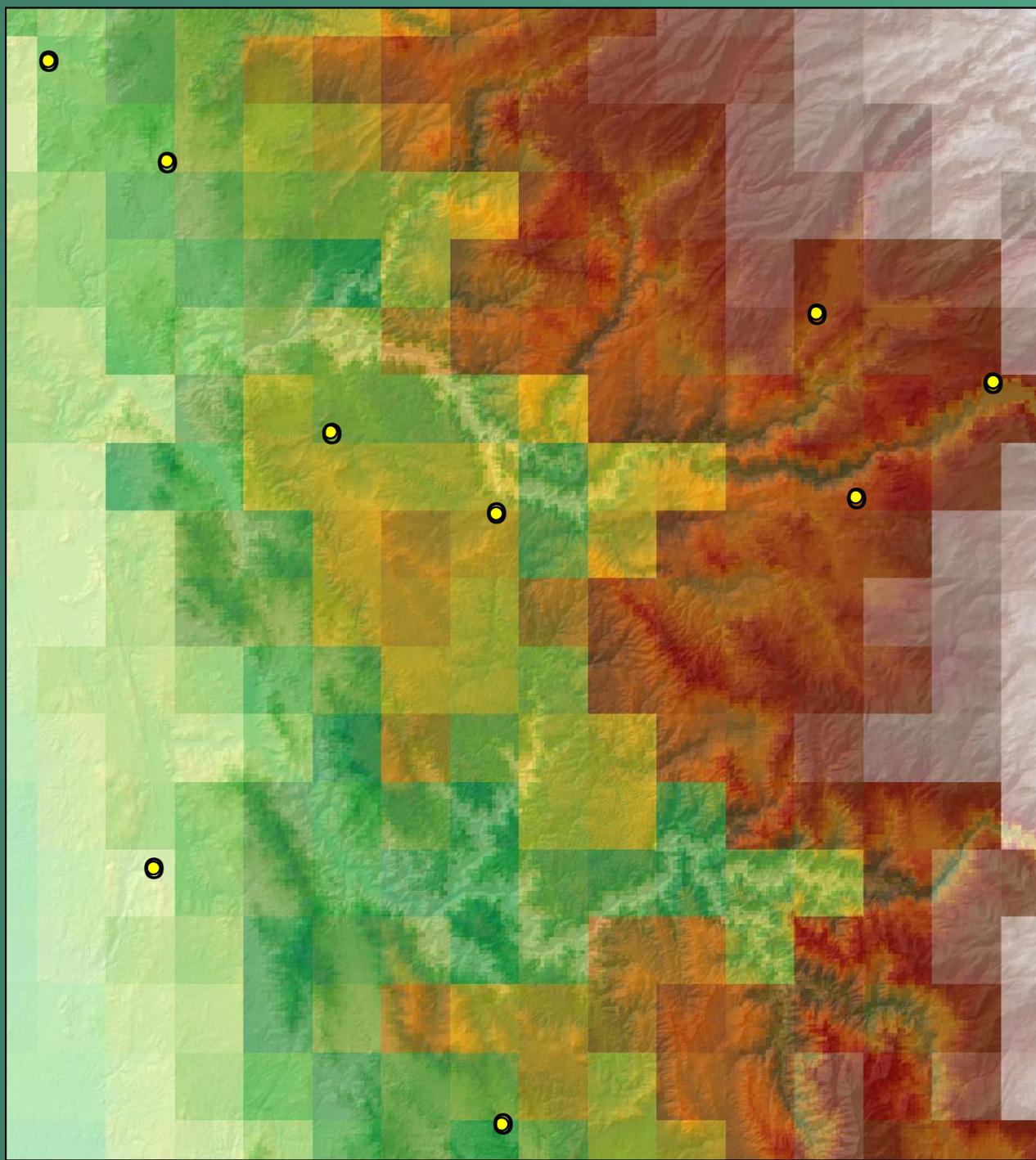


# Processing of Climate Change Scenarios

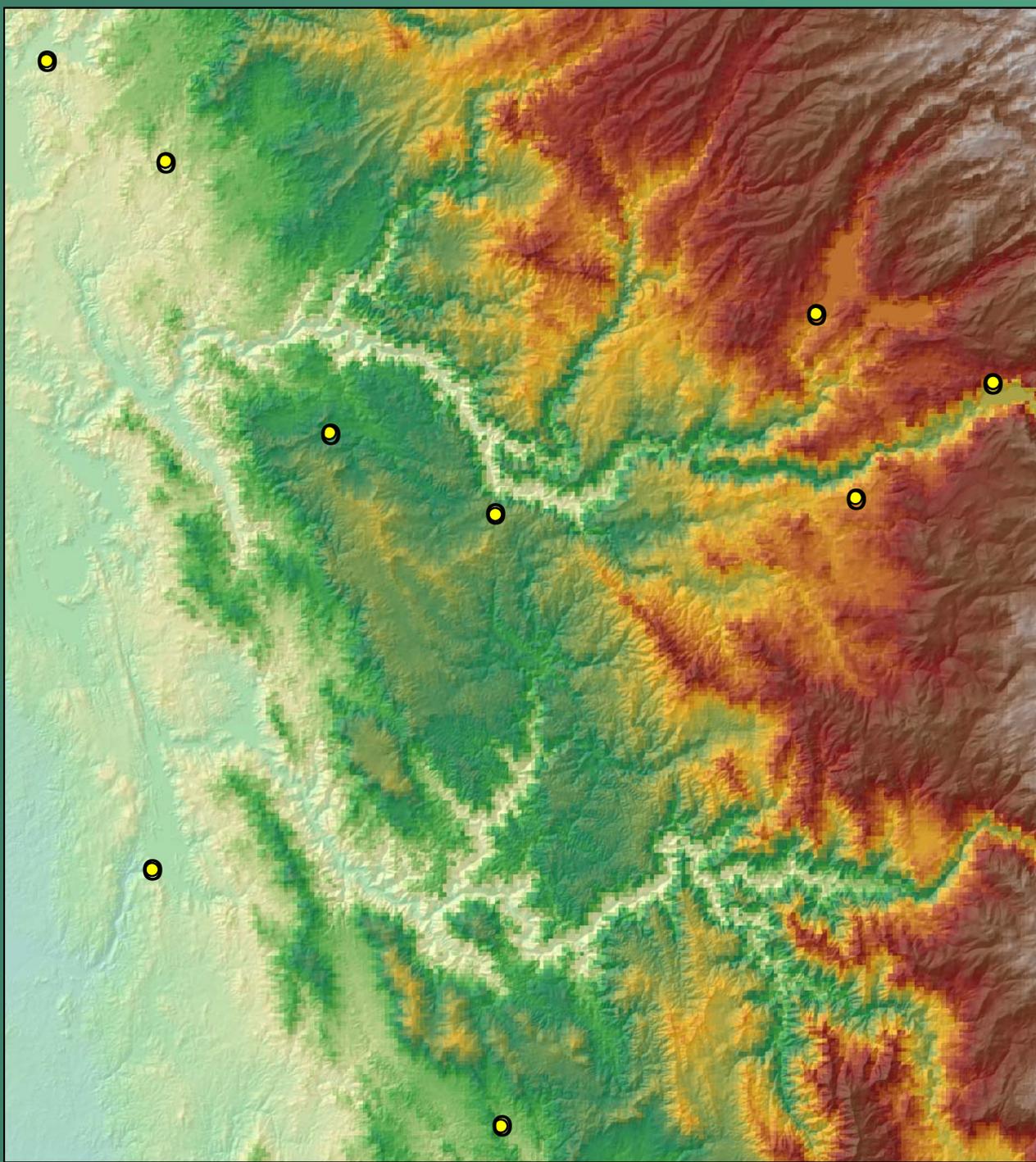
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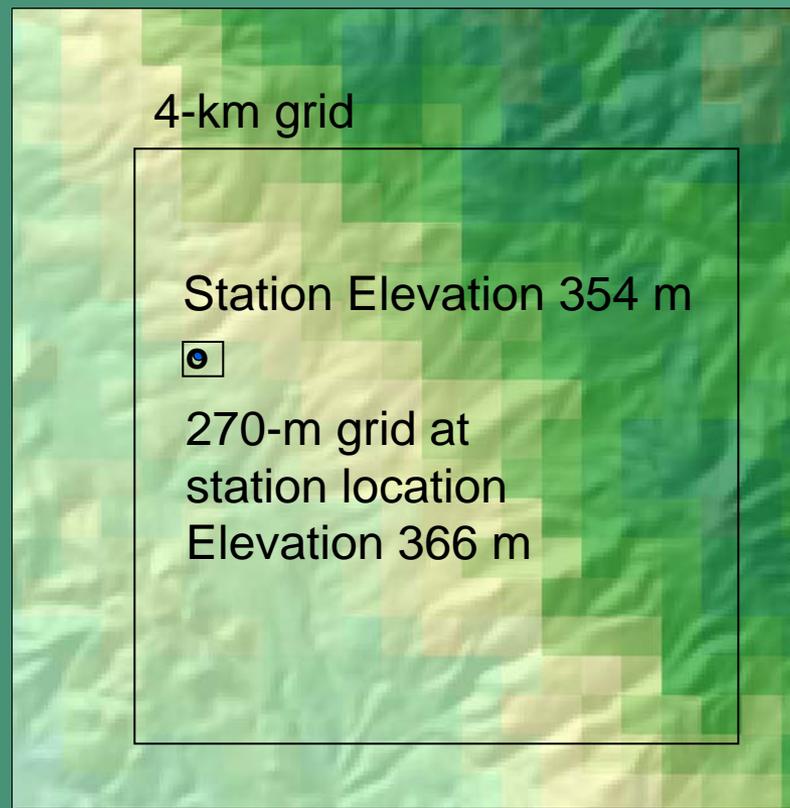


4-km  
grid cells

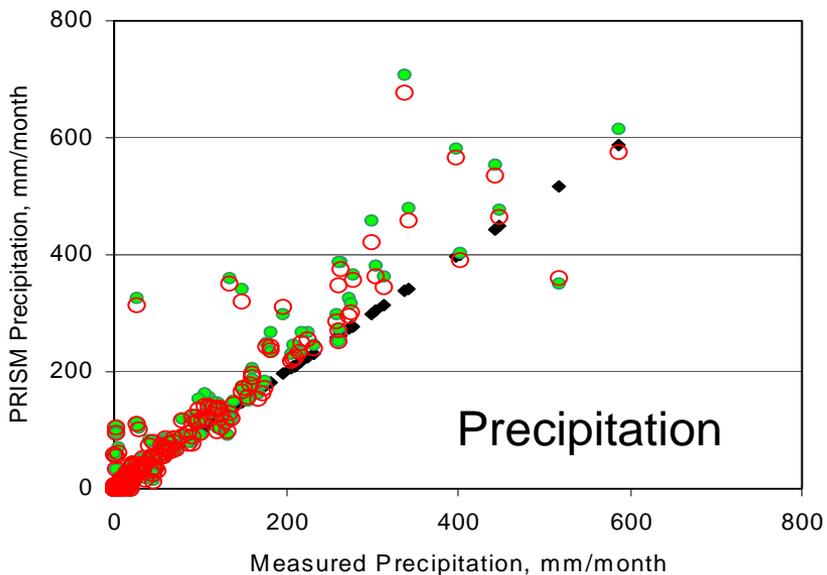


270-m  
grid cells

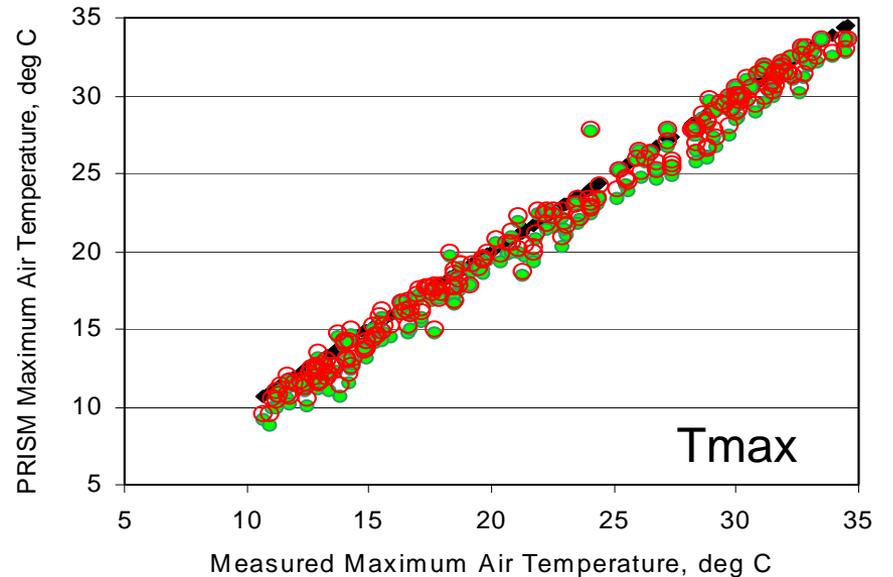
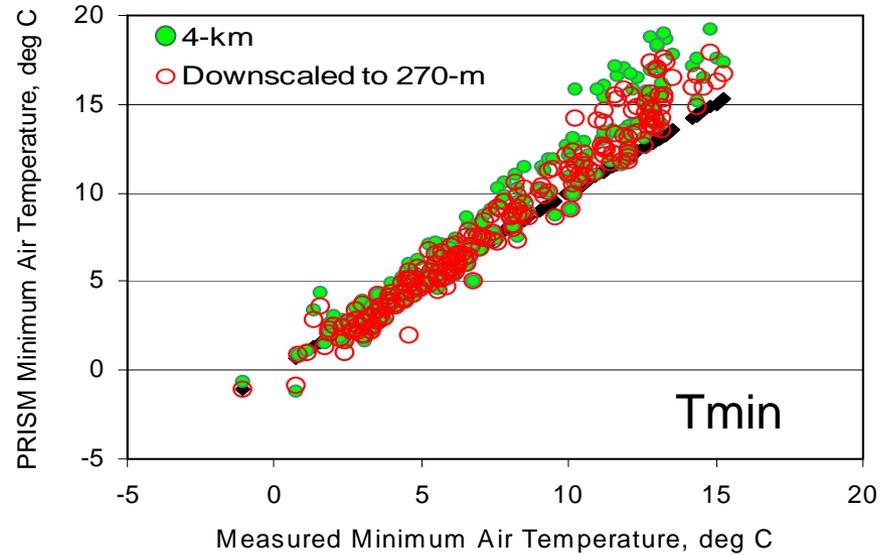


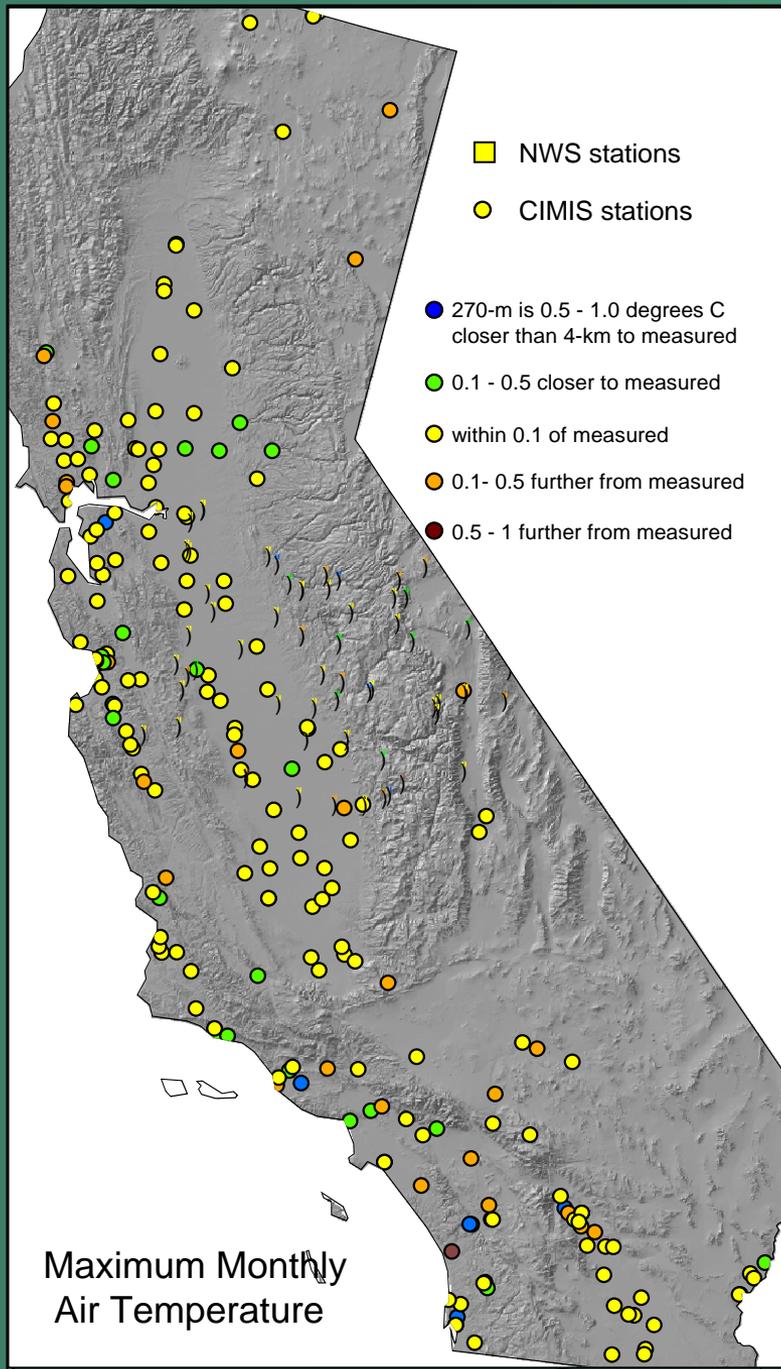


# Comparison of climate parameter estimates of 4-km grid and downscaled 270-m grid to measured data for Hopland FS CIMIS station



◆ CIMIS measured data ● PRISM 4 km ○ PRISM Downscaled to 270 m





Compared measured monthly

Precipitation

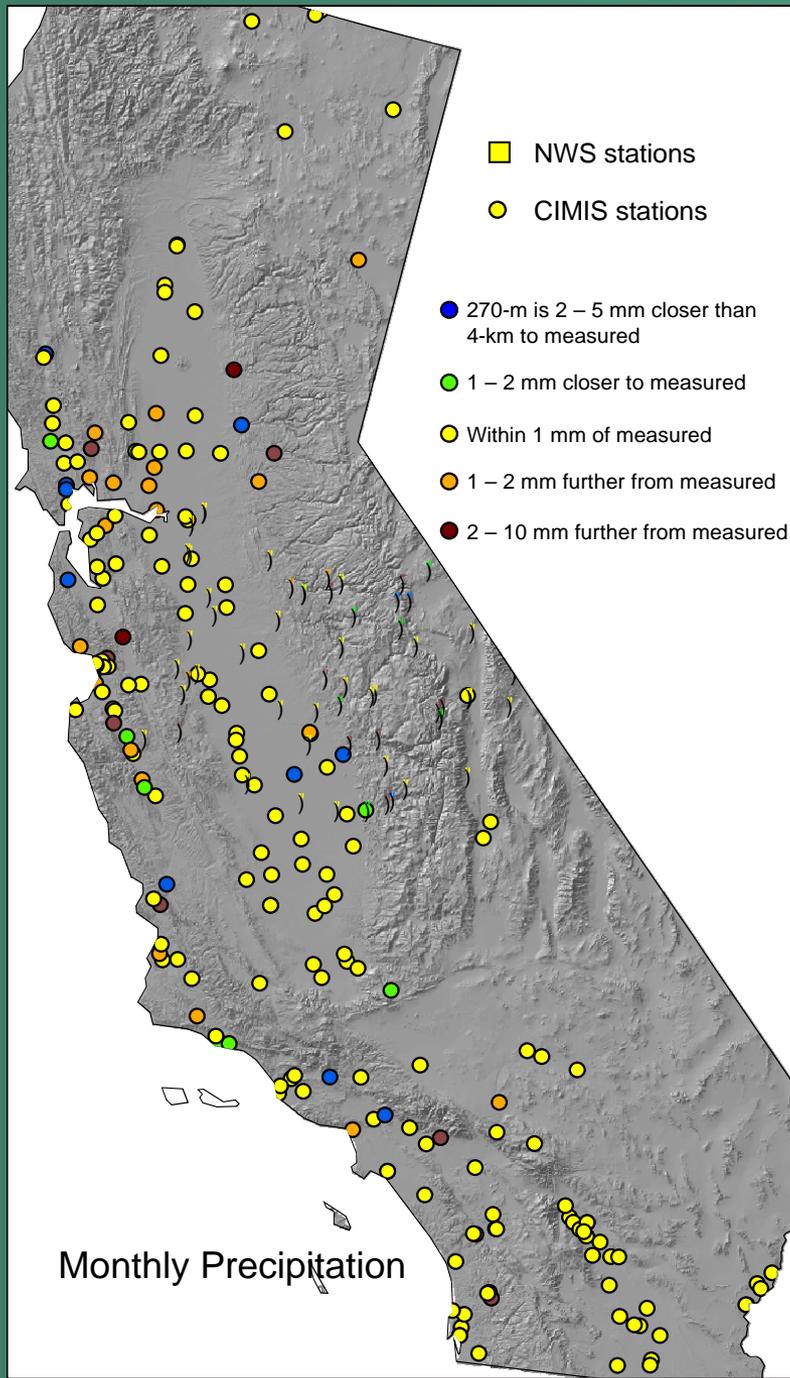
Maximum air temperature

Minimum air temperature

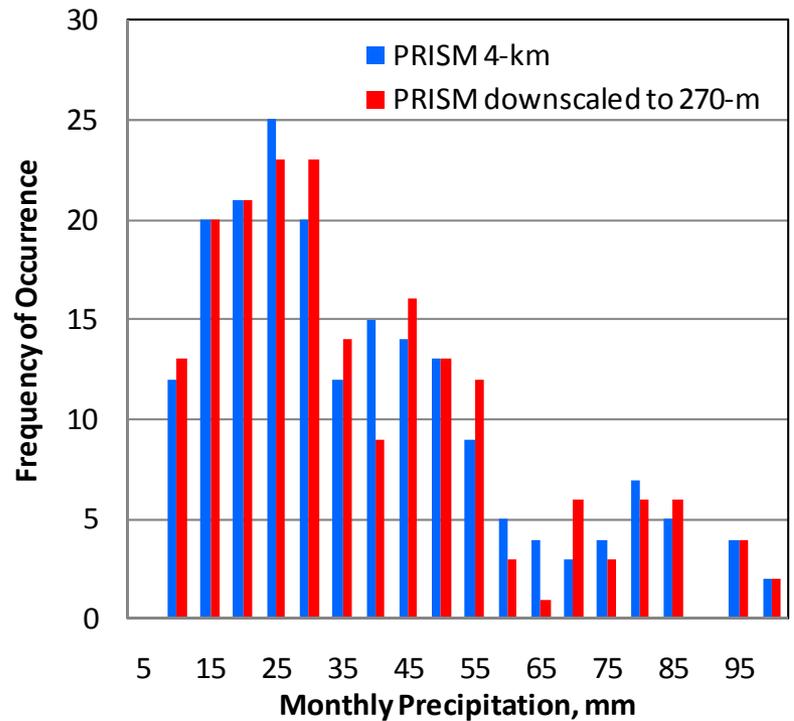
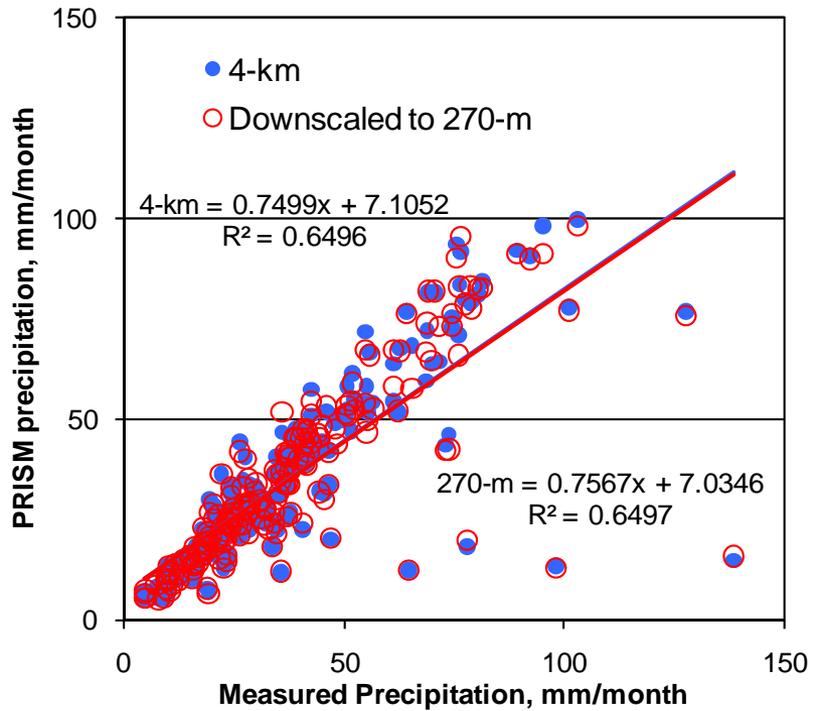
and

4-km PRISM

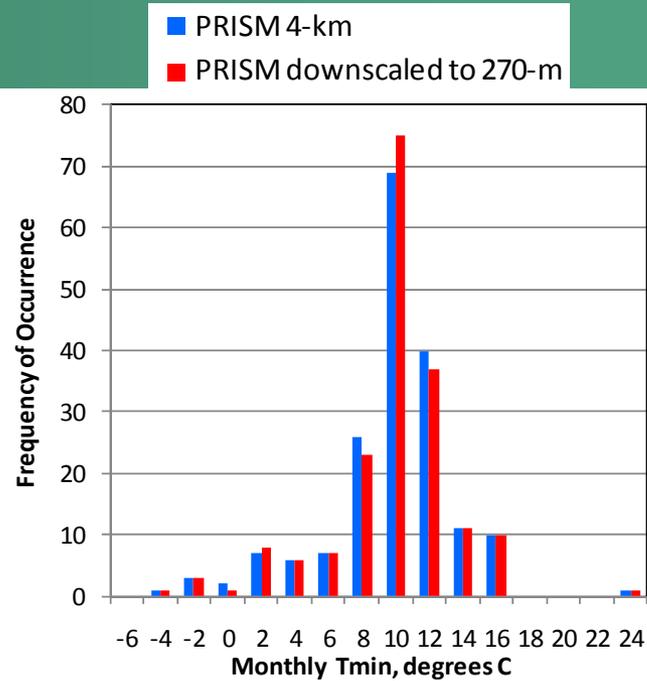
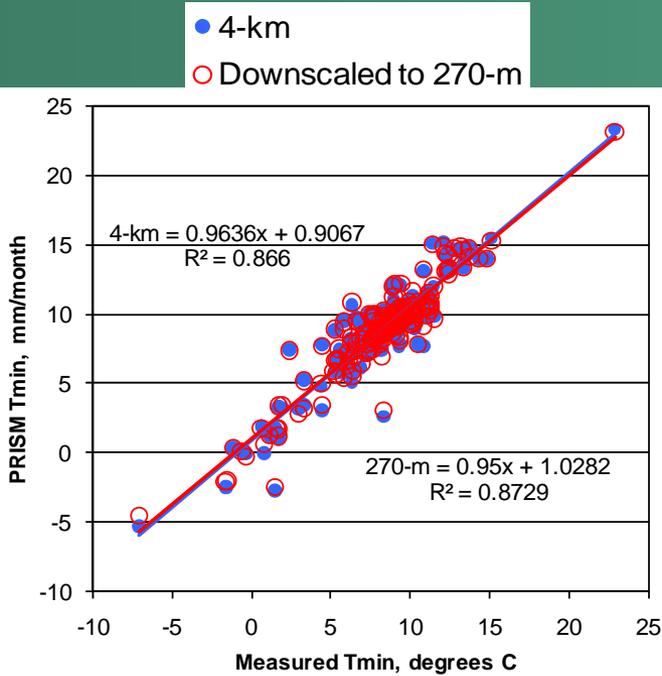
Downscaled 270-m PRISM



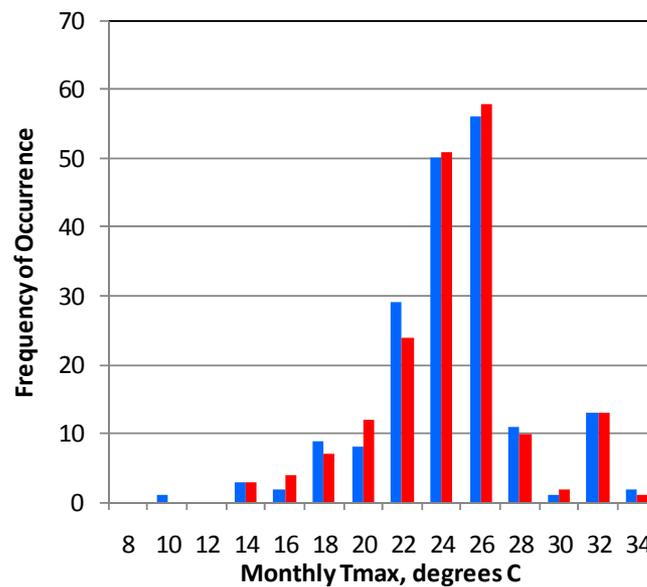
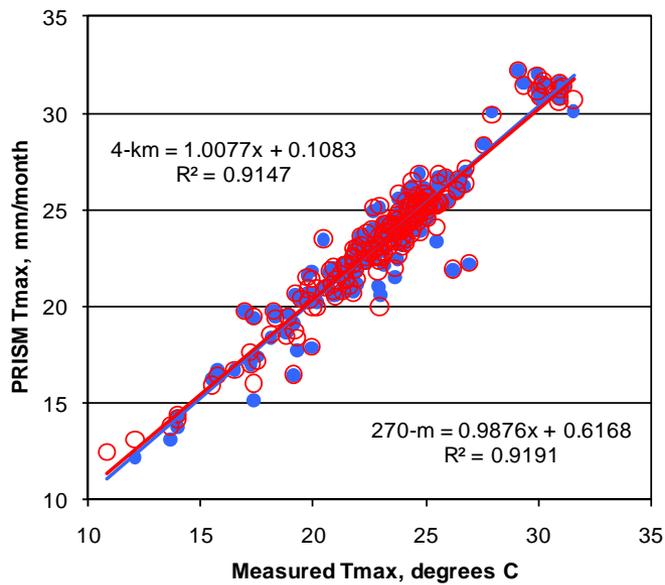
# Monthly Precipitation



# Minimum Monthly Air Temp



# Maximum Monthly Air Temp



## Means and standard deviations

measured climate parameters

PRISM climate parameters for 4-km cells

PRISM climate parameters for 270-m cells

|  |         | Measured | PRISM<br>4-km | PRISM<br>downscaled to<br>270-m | Number of<br>stations |
|--|---------|----------|---------------|---------------------------------|-----------------------|
| Precipitation<br>(mm/month)            | mean    | 38.1     | 35.8          | 35.7                            | 195                   |
|  | std dev | 23.8     | 22.4          | 22.2                            |                       |
| Minimum Air Temperature<br>(degrees C) | mean    | 8.2      | 8.8           | 8.8                             | 183                   |
|  | std dev | 3.5      | 3.7           | 3.6                             |                       |
| Maximum Air Temperature<br>(degrees C) | mean    | 23.2     | 23.5          | 23.5                            | 185                   |
|  | std dev | 3.5      | 3.7           | 3.6                             |                       |

# Downscaling Conclusions

- Constructed analogues technique provides a rigorous approach to downscaling GCM data to regional scales
- GIDS approach to downscaling climate parameters to a fine resolution generally maintains or improves accuracy by incorporating deterministic features represented by topographic relief



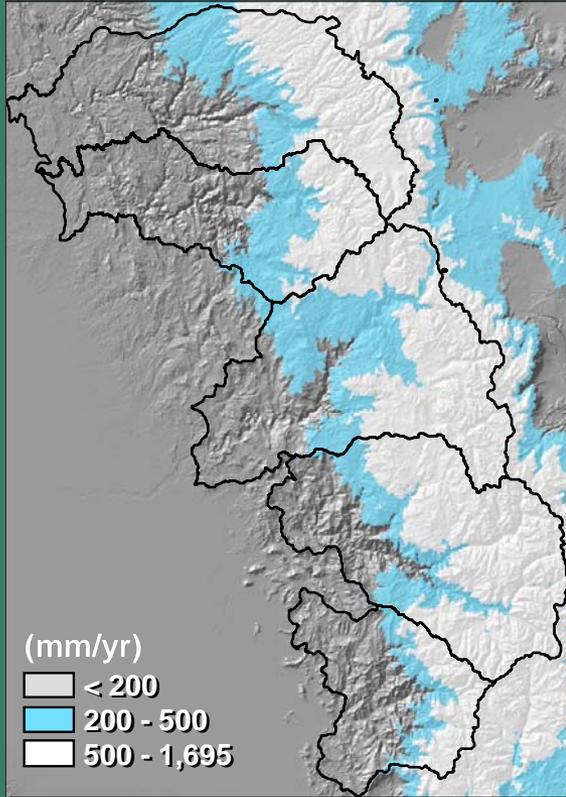
# Hydrologic Modeling

- Basin Characterization Model (BCM)
  - run in FORTRAN
  - uses grid-based data
  - calculates in-place recharge or generated runoff
- Potential evapotranspiration (Priestley-Taylor)
  - hourly solar radiation modeled using topographic shading and cloudiness
  - vegetation density
- Snow accumulation and melt based on NWS Snow-17 Model
- Soils (STATSGO/SSURGO): hydraulic properties and depth determine soil storage
- Geology is used to estimate bedrock permeability
- Precipitation and air temperature is available using PRISM datasets or future projections

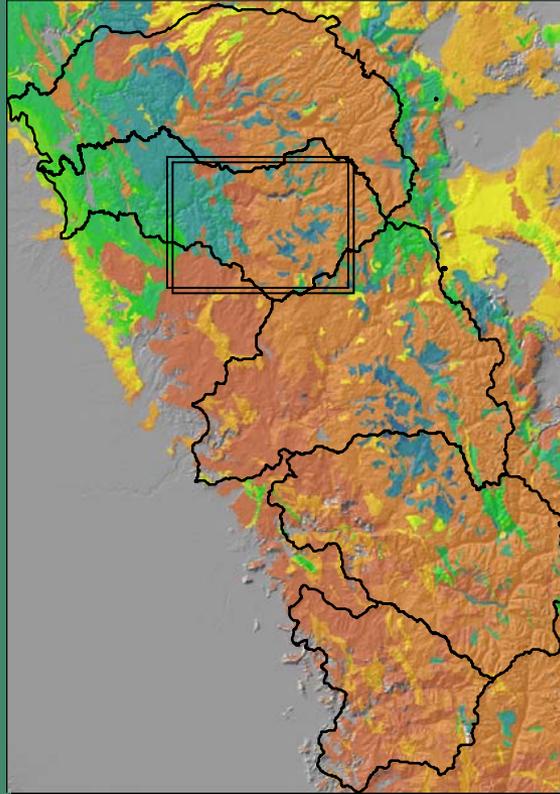


# Regional Hydrologic Modeling

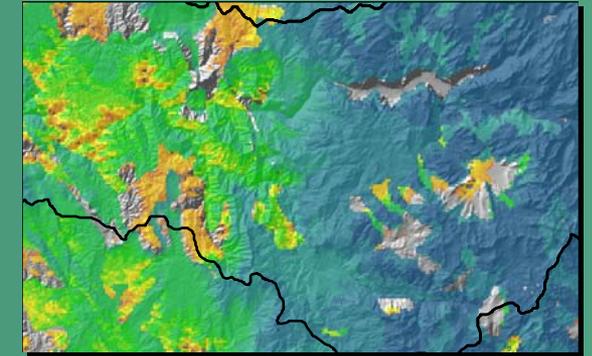
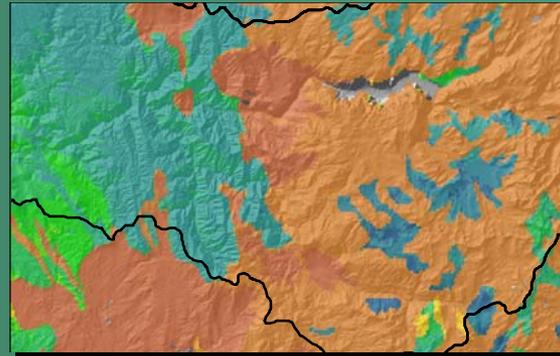
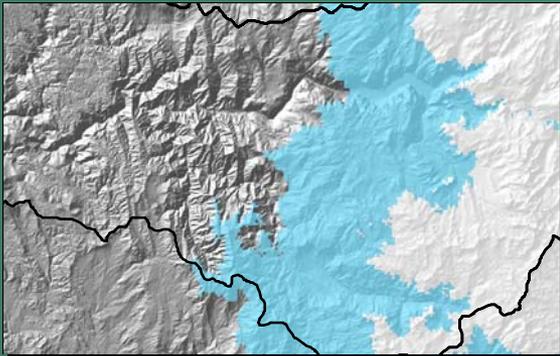
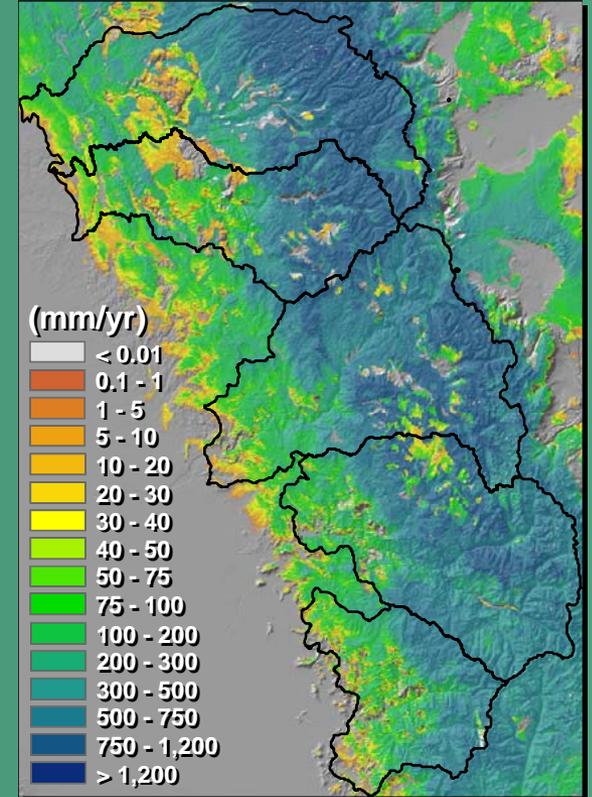
## Average Annual Snowpack



## Average Annual Recharge



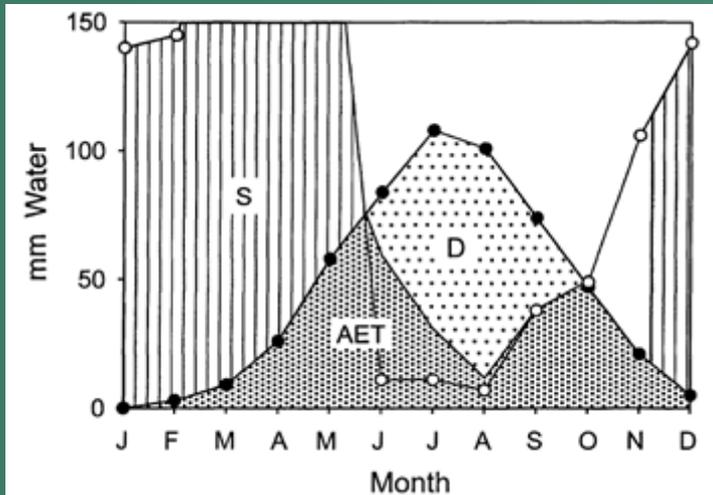
## Average Annual Runoff



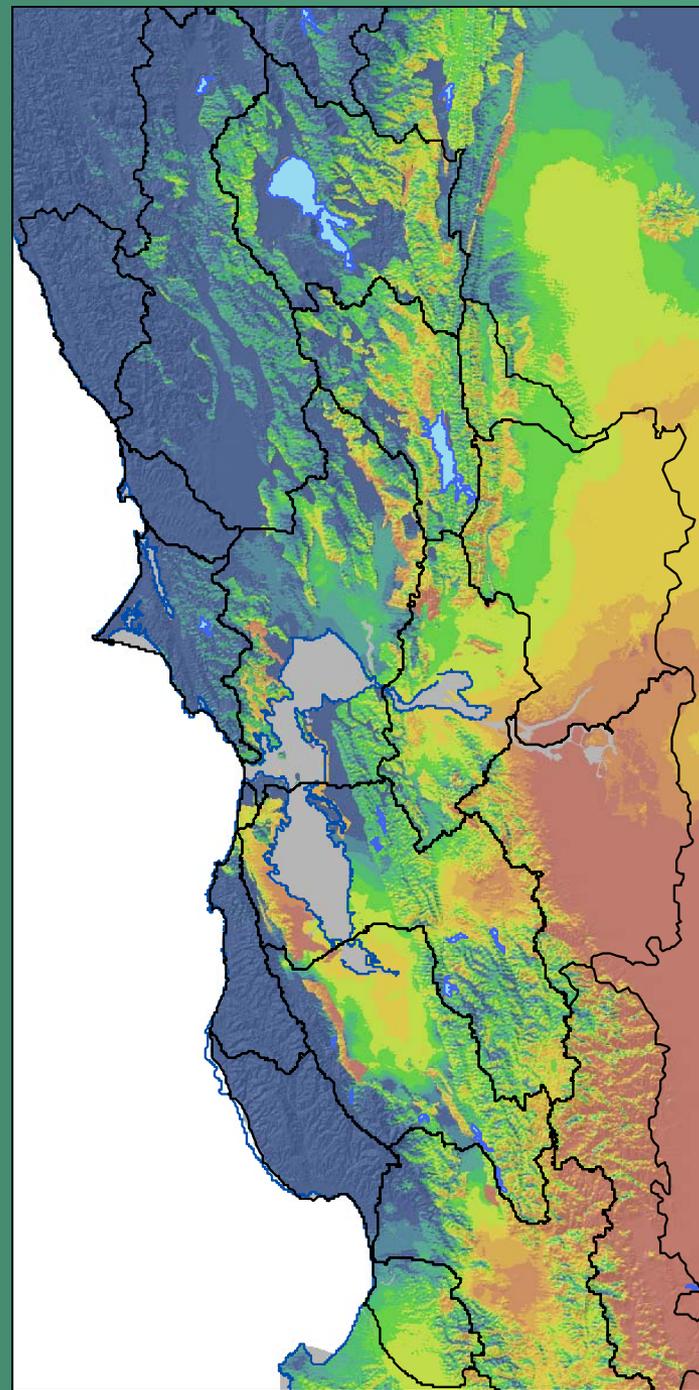
# Climatic Water Deficit

Annual evaporative  
demand  
that exceeds  
available water

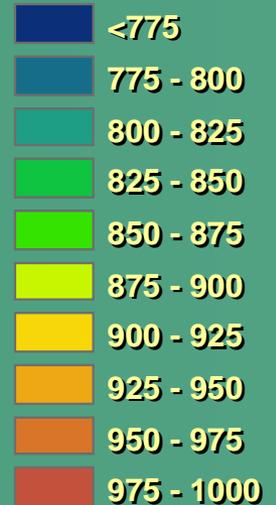
Potential – Actual  
Evapotranspiration

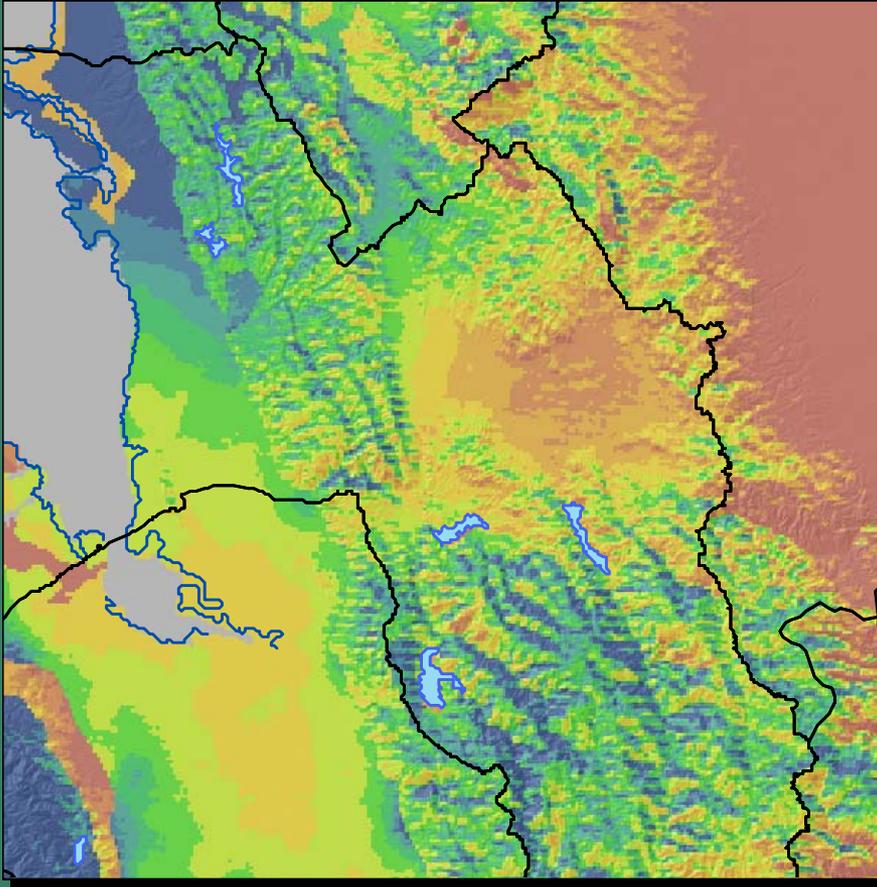


*From Stephenson, 1998*

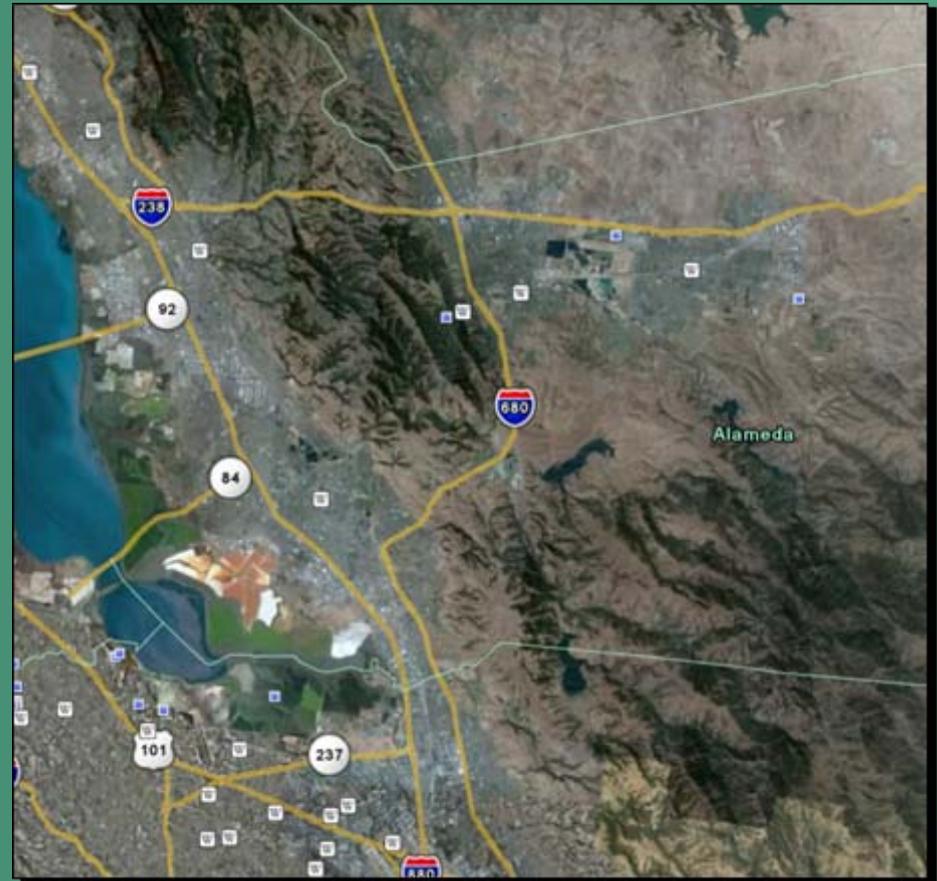


**2001**  
(mm/yr)



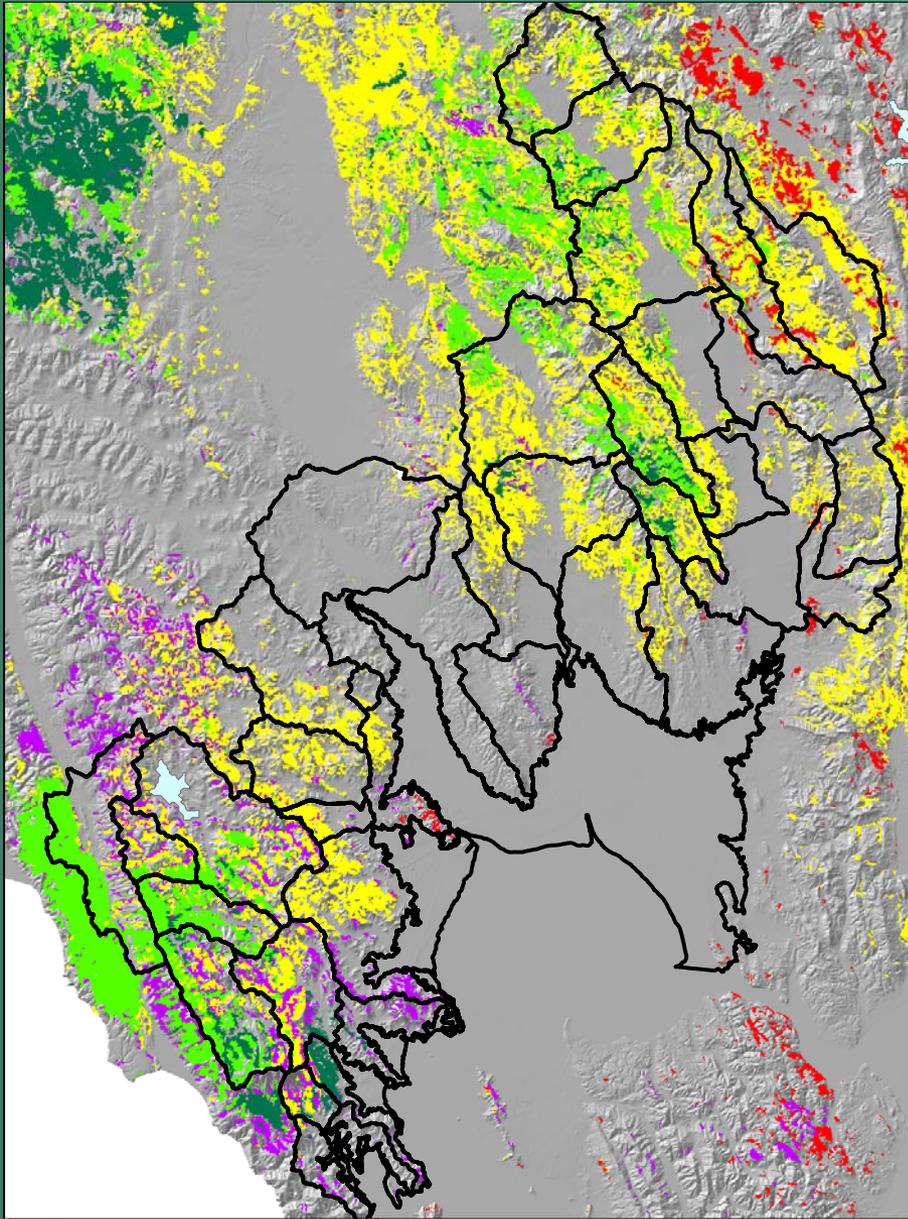


*Climatic Water Deficit in South Bay*



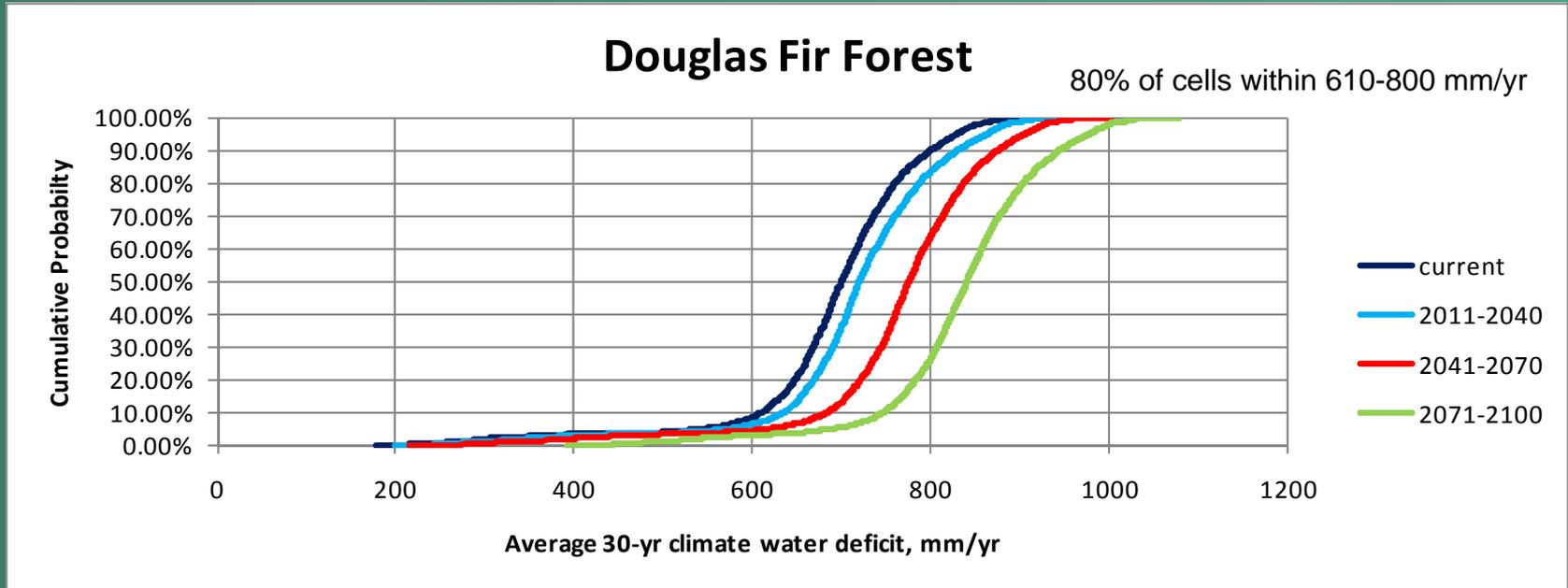
*Google Maps Image of South Bay*

# North Bay Vegetation Types



-  Blue Oak Forest / Woodland
-  California Bay Forest
-  Douglas Fir Forest
-  Montane Hardwoods
-  Redwood Forest

# Climatic Water Deficit Envelopes

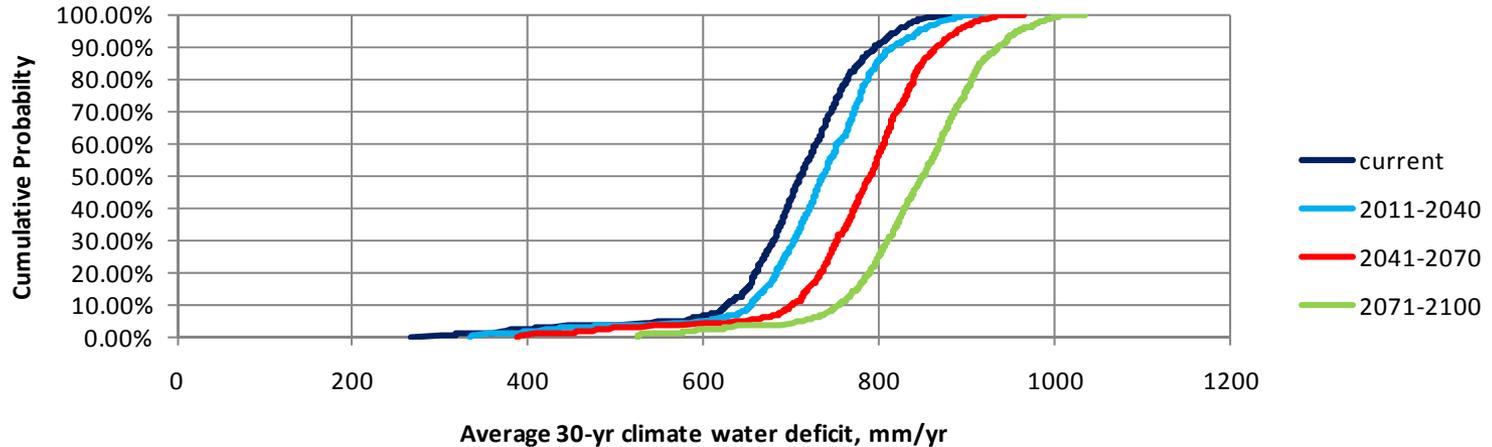


*GFDL-A2 scenario*

# Climatic Water Deficit Envelopes

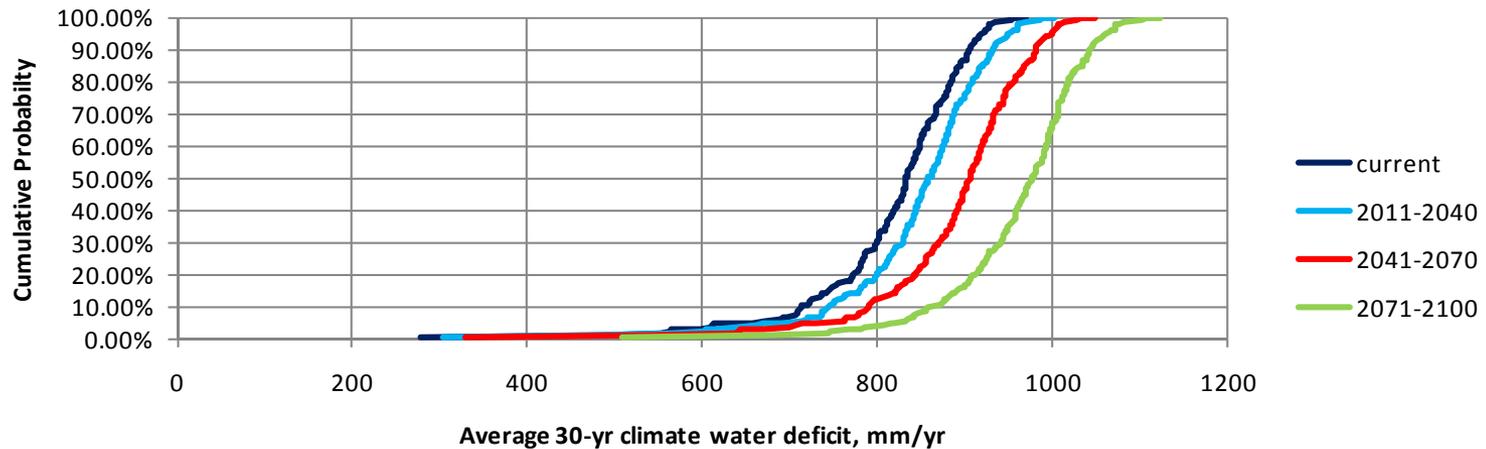
## Redwood Forest

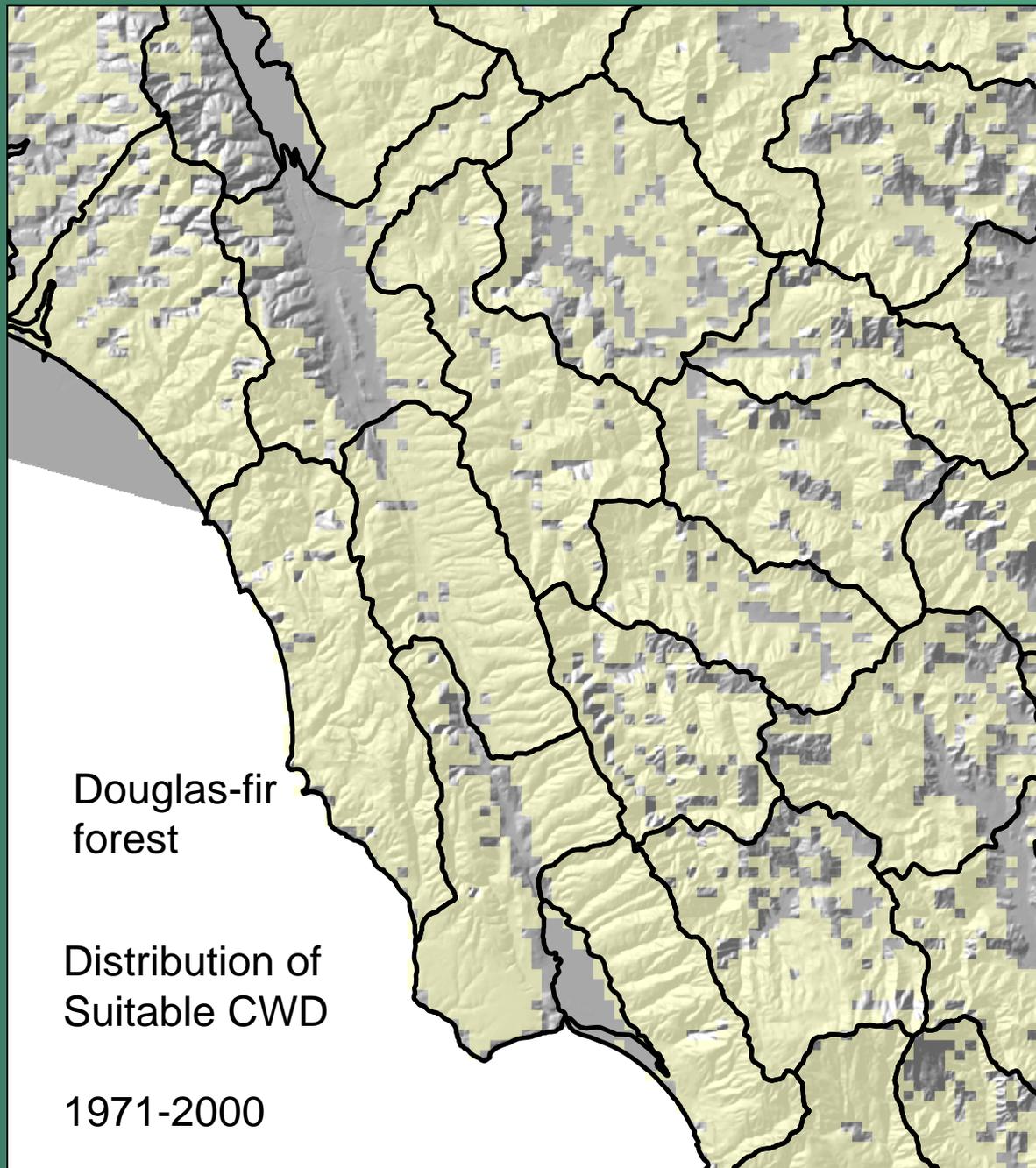
80% of cells within 640-800 mm/yr

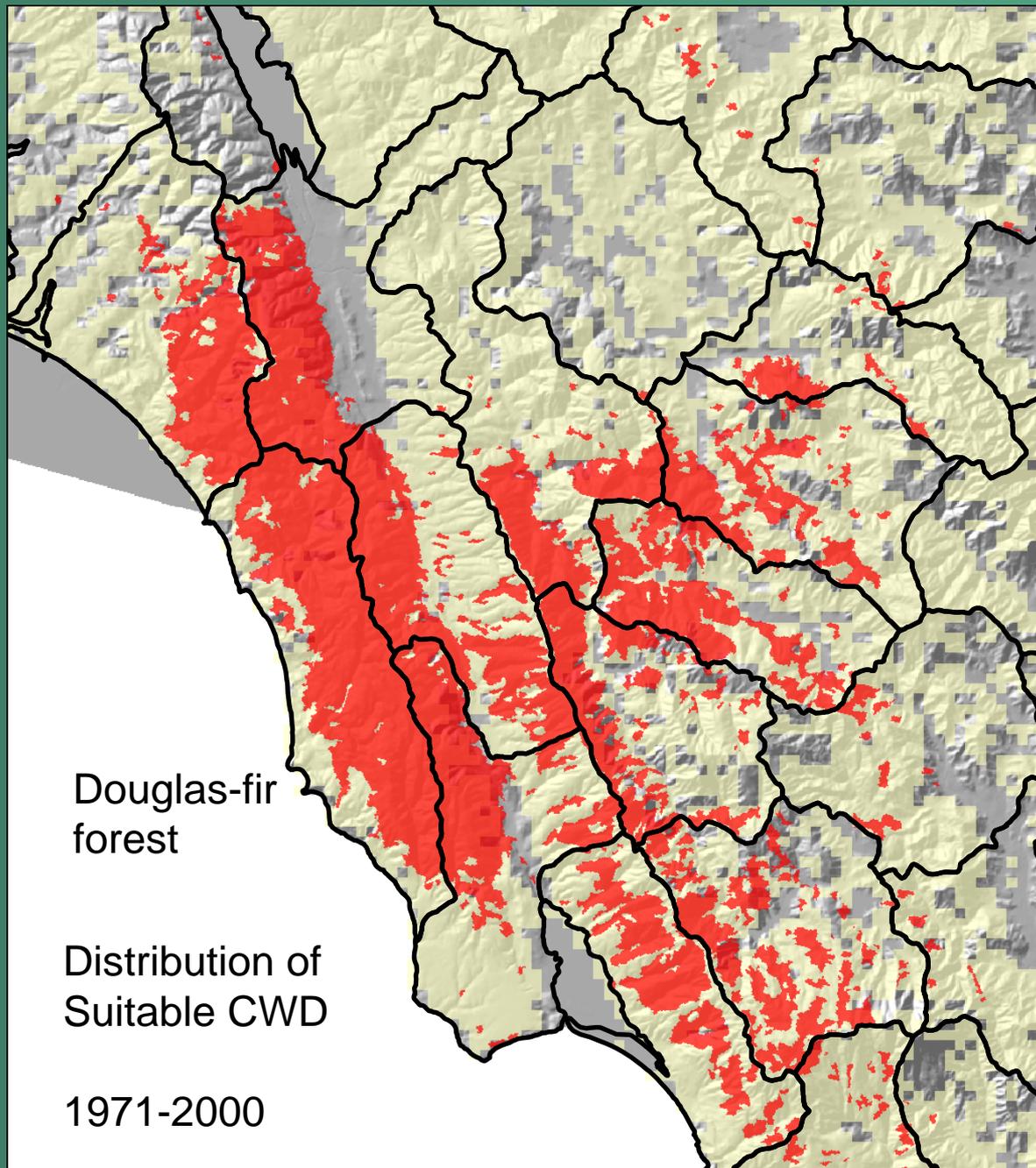


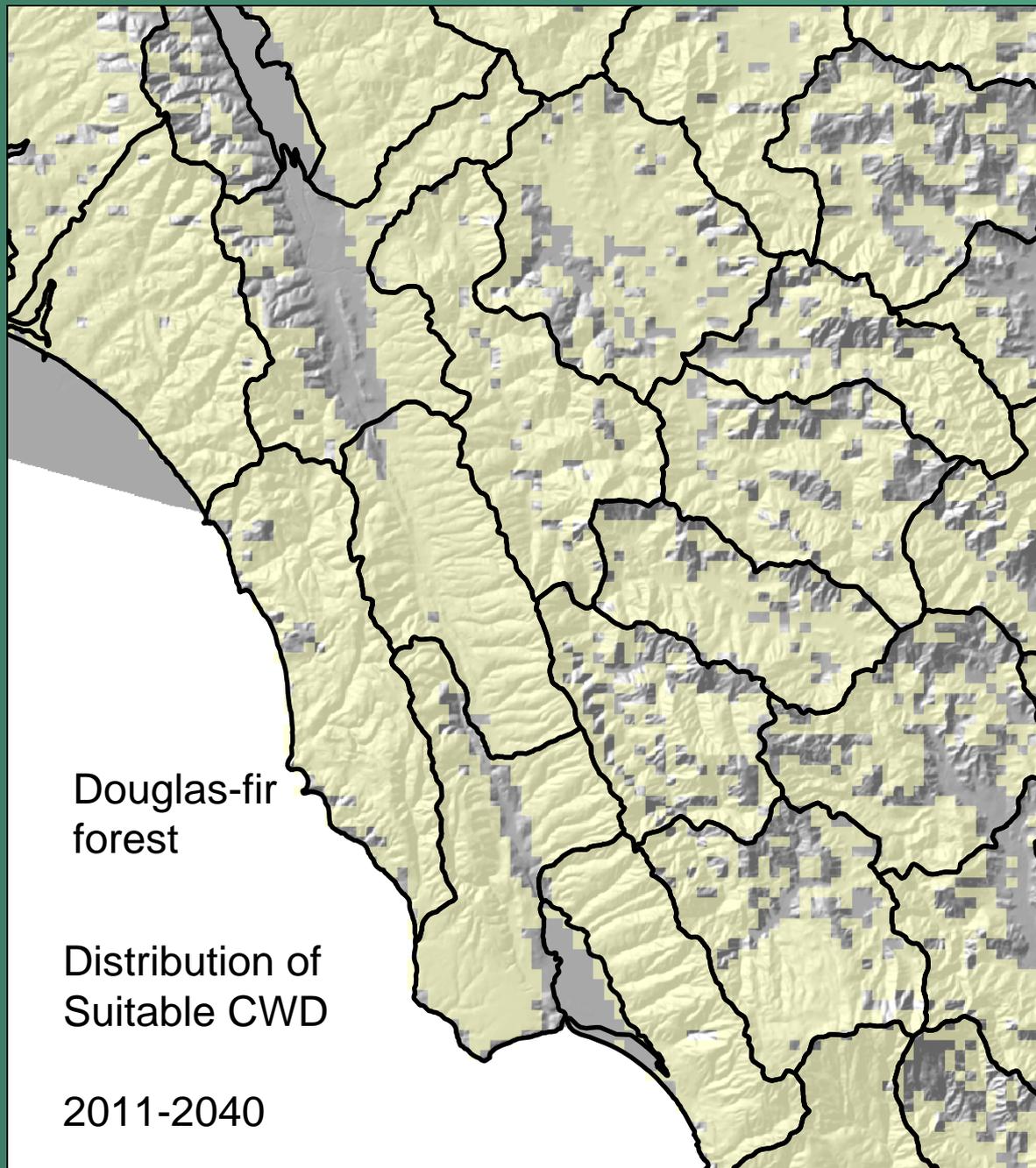
## Blue Oak Woodland

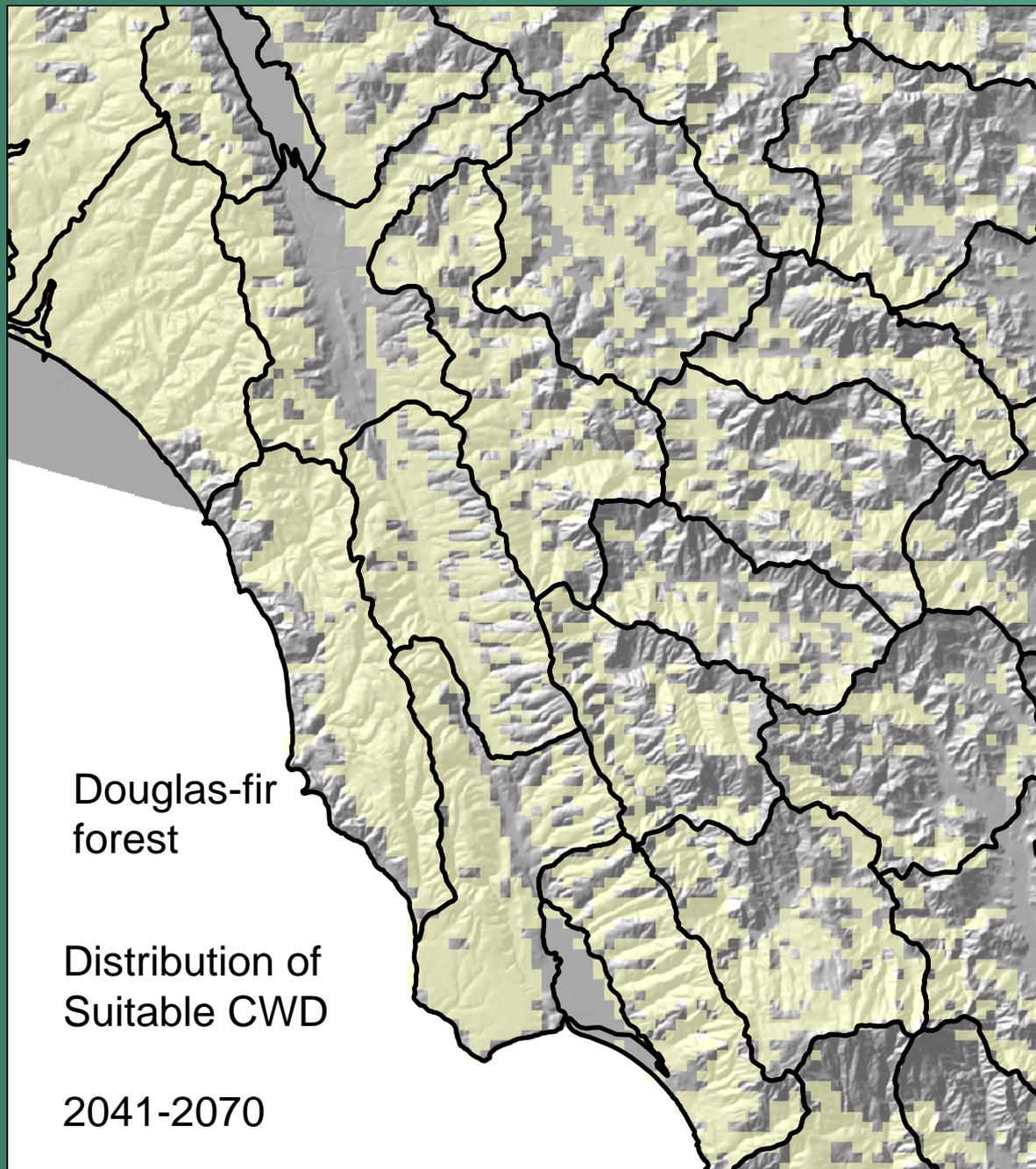
80% of cells within 710-900 mm/yr

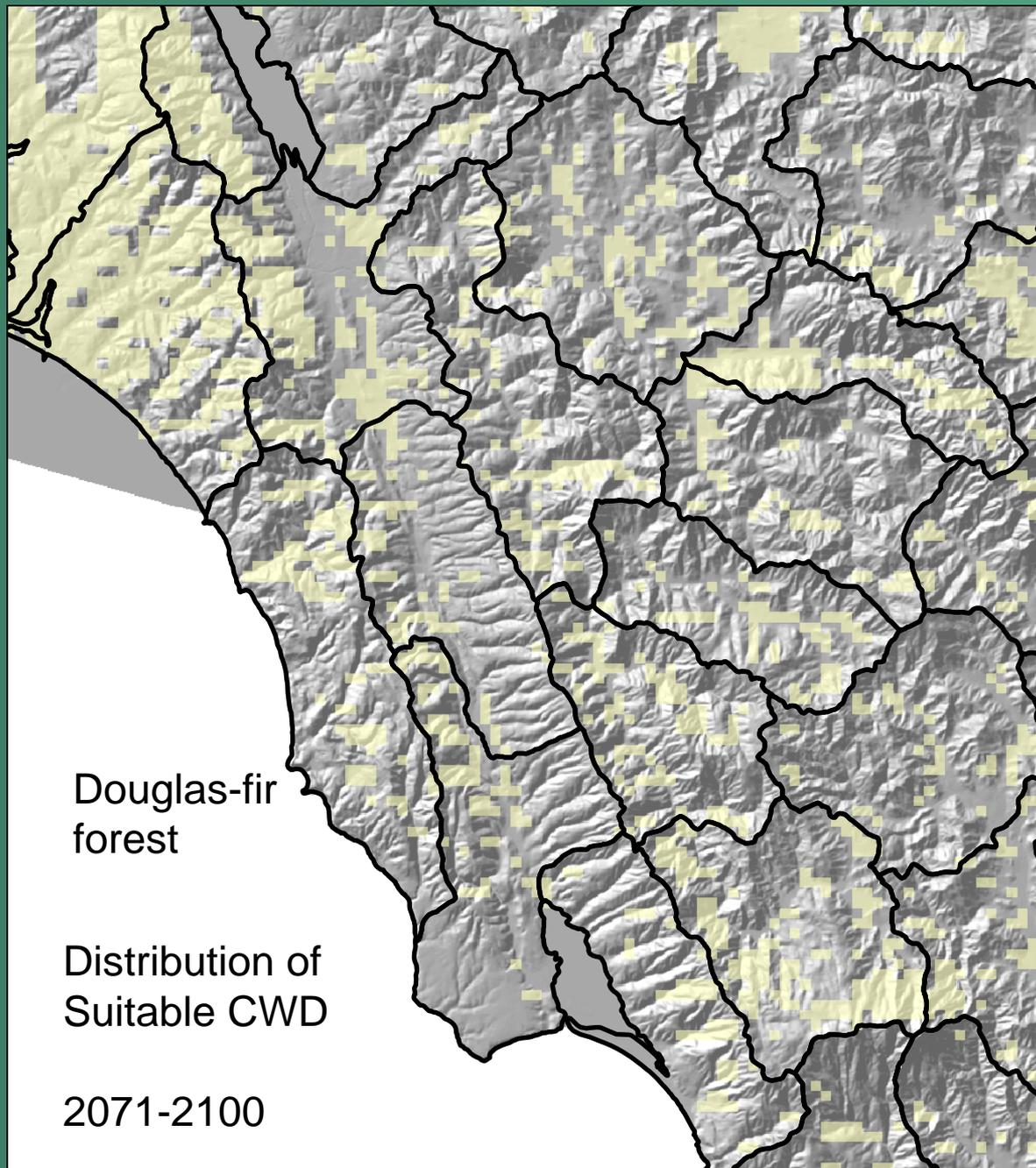


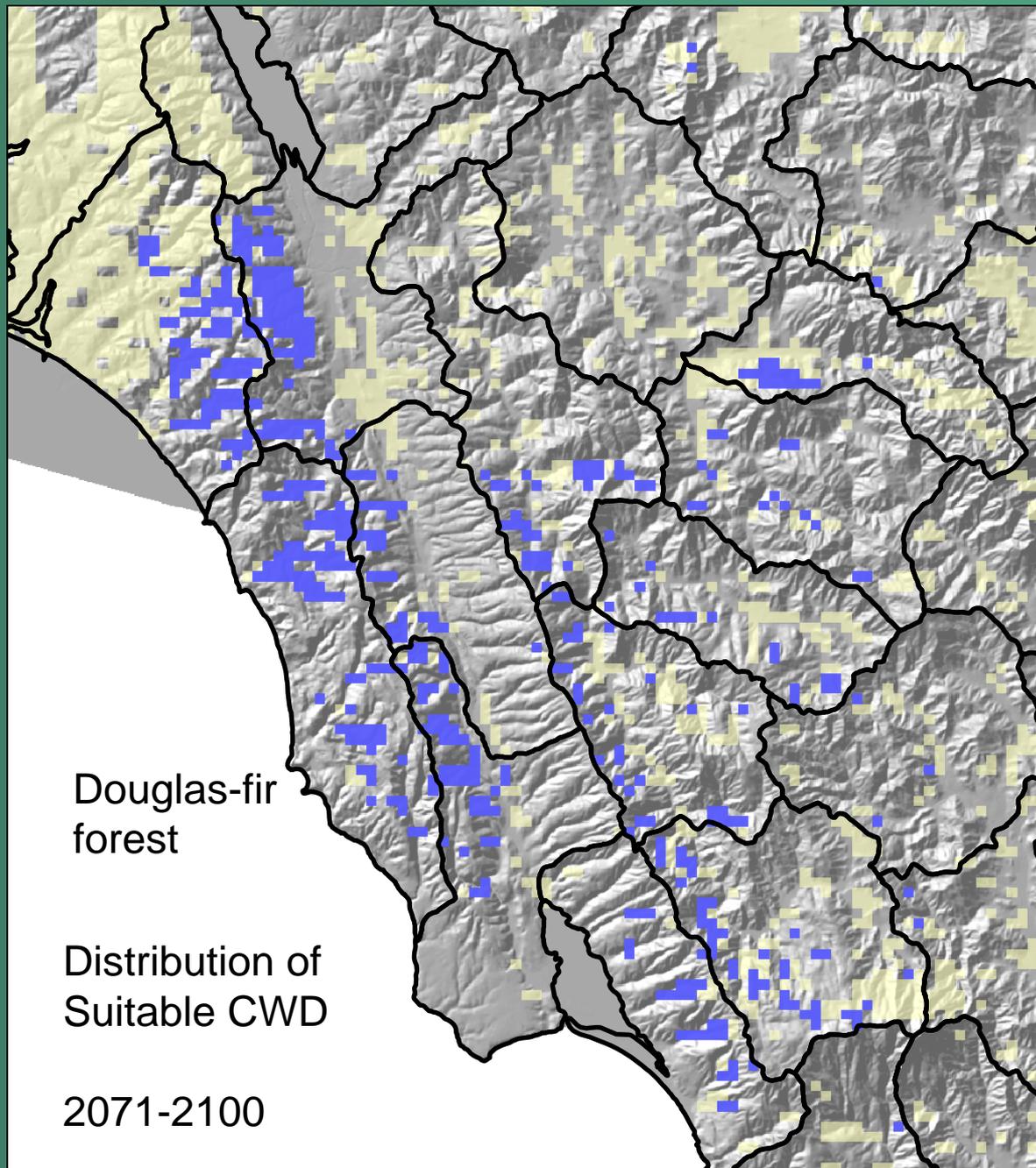


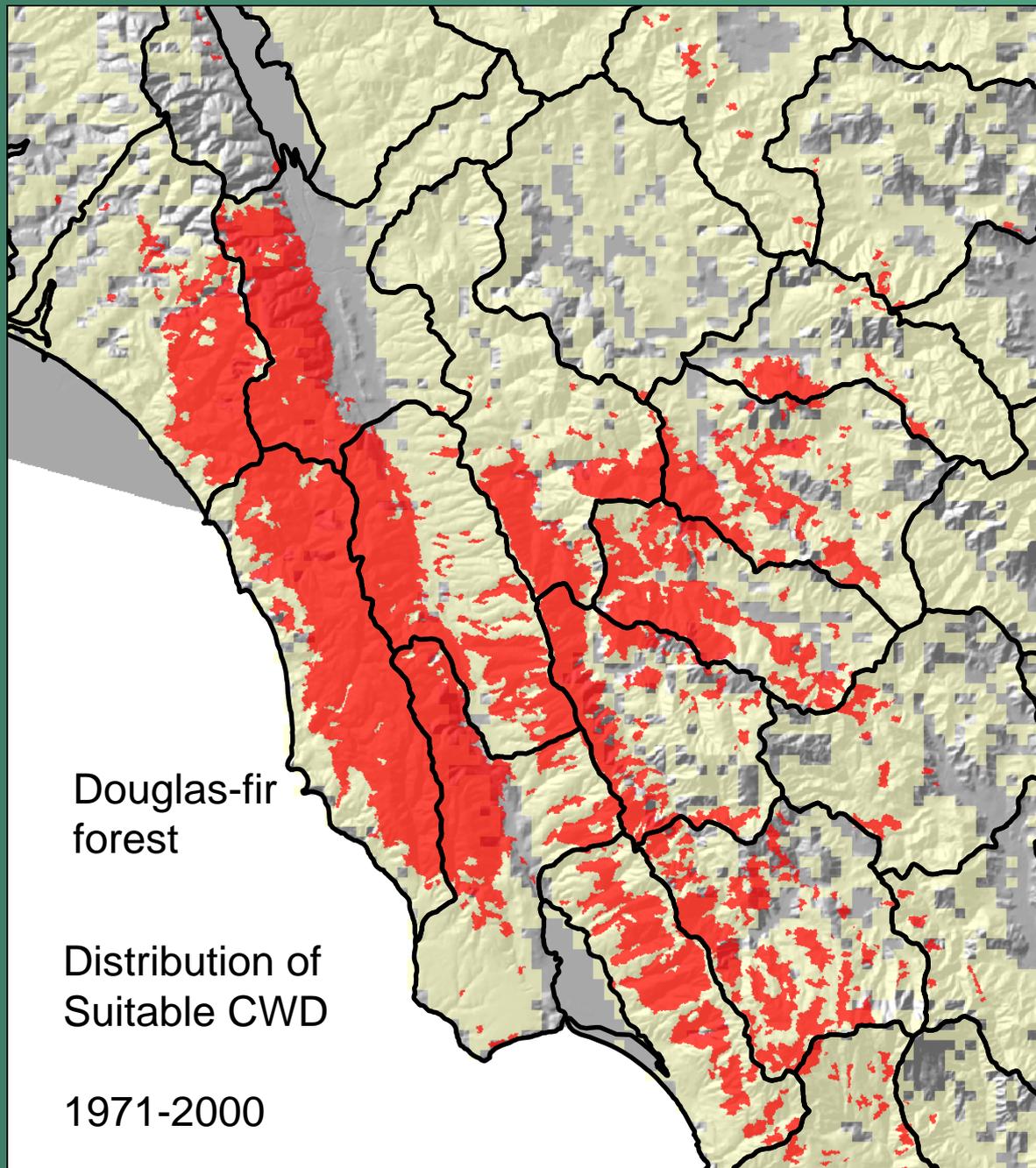


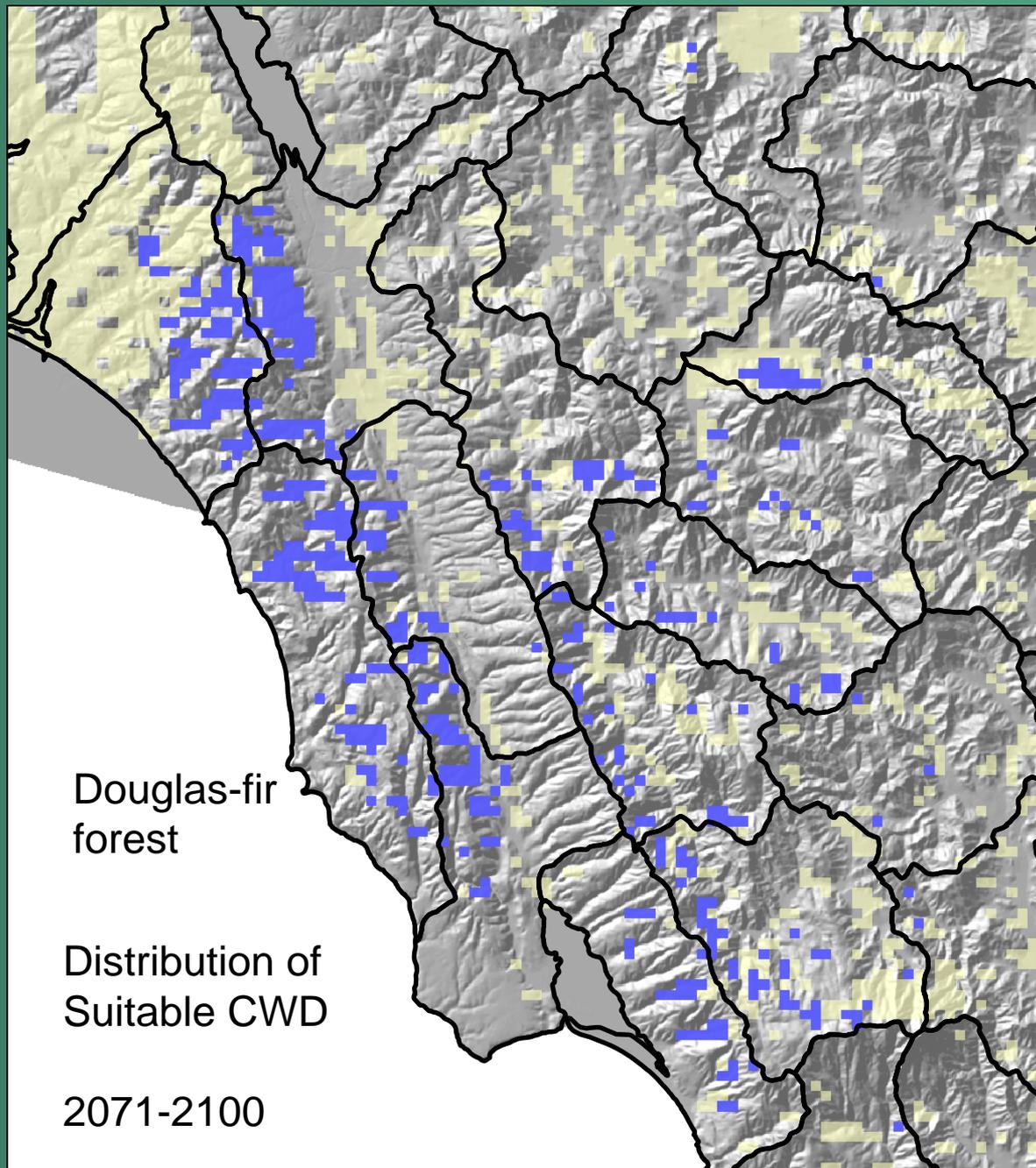




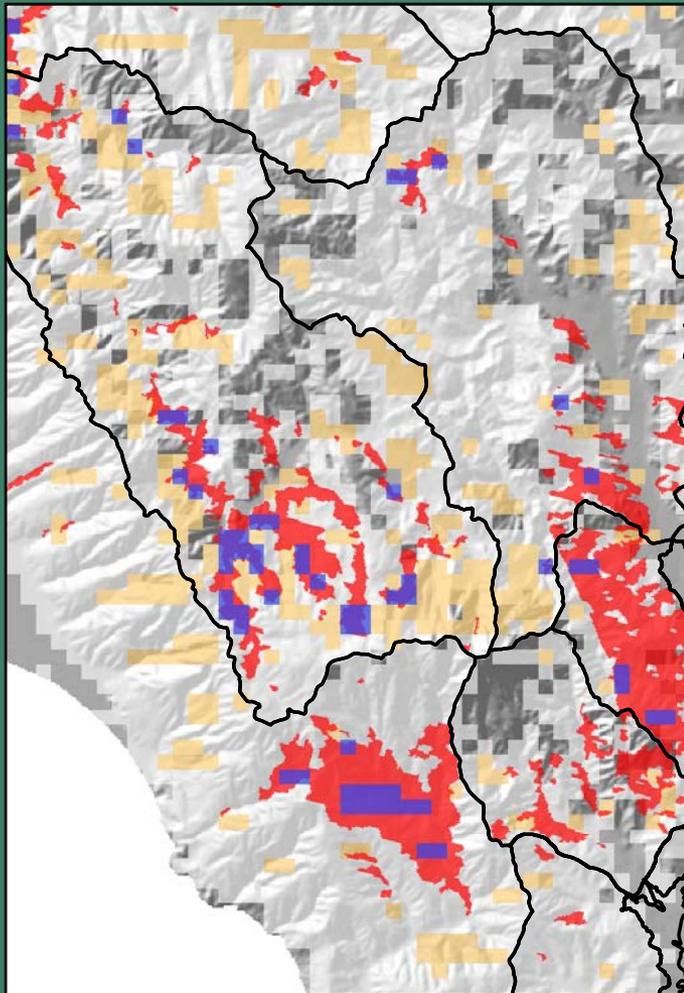






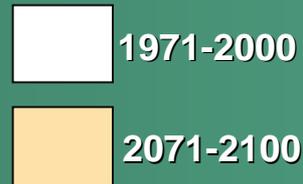


# Climatic Water Deficit and Climate Change

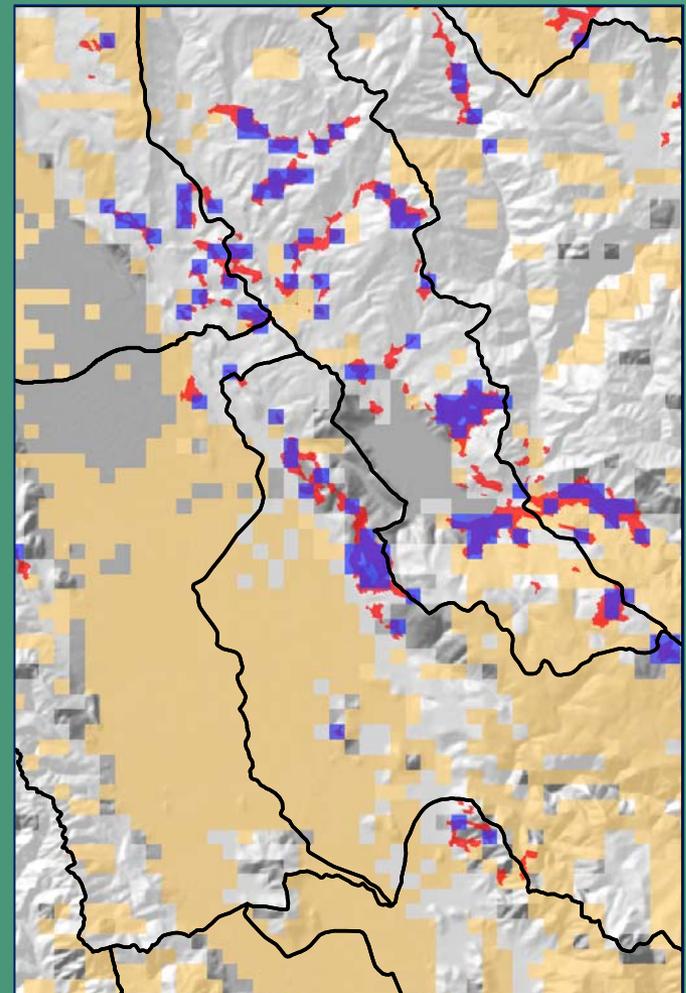
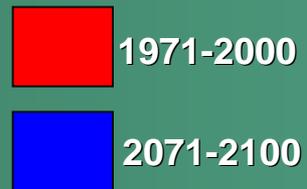


**Redwood forest**

Distribution of  
suitable CWD



Distribution of  
vegetation type



**Blue oak forest/woodland**

# Summary

- GCM output needs to be downscaled for intended application
  - Scale of resolution
    - Regional or local processes
    - Translation through hydrology models provide impacts of the interrelated processes
- Constructed analogues and GIDS approaches provide rigor as well as options for analysis at multiple scales
- Application of climate projections at fine scales
  - Provides simulations of environmental conditions that occur at the hillslope scale
  - Reflects energy loading processes and changes in soil conditions
  - Correlate to the distribution of vegetation types



