Climate Change Trends & Impacts California's Agriculture: Temperature & Rainfall

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University of California
Agriculture and Natural Resources

Outline

- Facts about agriculture in California
- Climate basics
- Observed and Projected Trends
  - Temperature
  - Precipitation
  - Extreme events
  - Snowpack
- Agricultural Impacts
  - Yield declines
  - Chill accumulations
  - Growing season shifts
  - Pests and Disease pressure
- Summary and Key research directions

Facts about California Agriculture

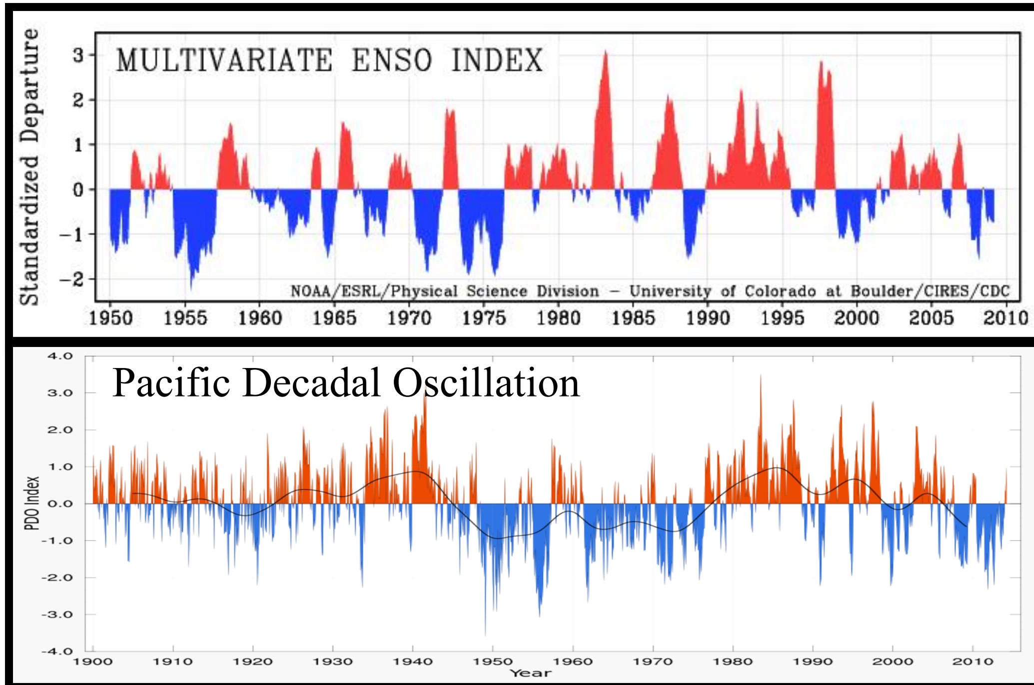
- 76,400 farms producing more than 400 commodities with a farm-gate value of $46 billion
- Of California's approximately 100 million acres of land, 43 million acres are used for agriculture
  - 16 million acres are grazing land, 27 million acres are cropland.
  - Only about 9 million acres of irrigated land
- Leading dairy production; 2/3 of US fruits and nuts production; 1/3 of US vegetable production

California's top—ten valued commodities

- Dairy, Milk — $6.07 billion
- Grapes — $5.5 billion
- Almonds — $5.1 billion
- Cattle, Calves — $2.5 billion
- Strawberries — $1.8 billion
- Lettuce — $1.9 billion
- Walnuts — $1.2 billion
- Tomatoes — $1.3 billion
- Pistachios — $1.5 billion
- Oranges — $826 million

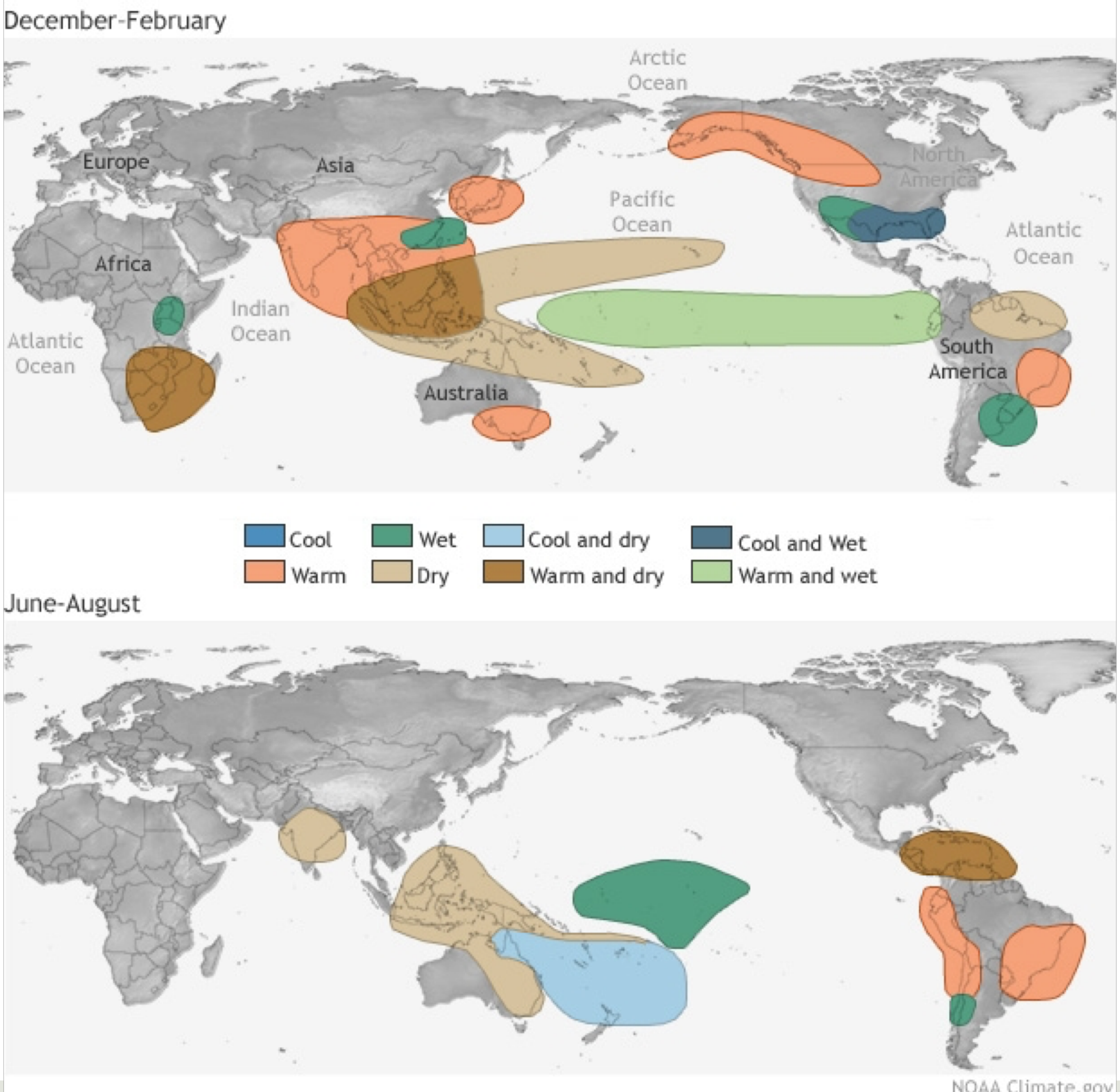
Information Source: CDFA, 2016

Climate Variability and Climate Change

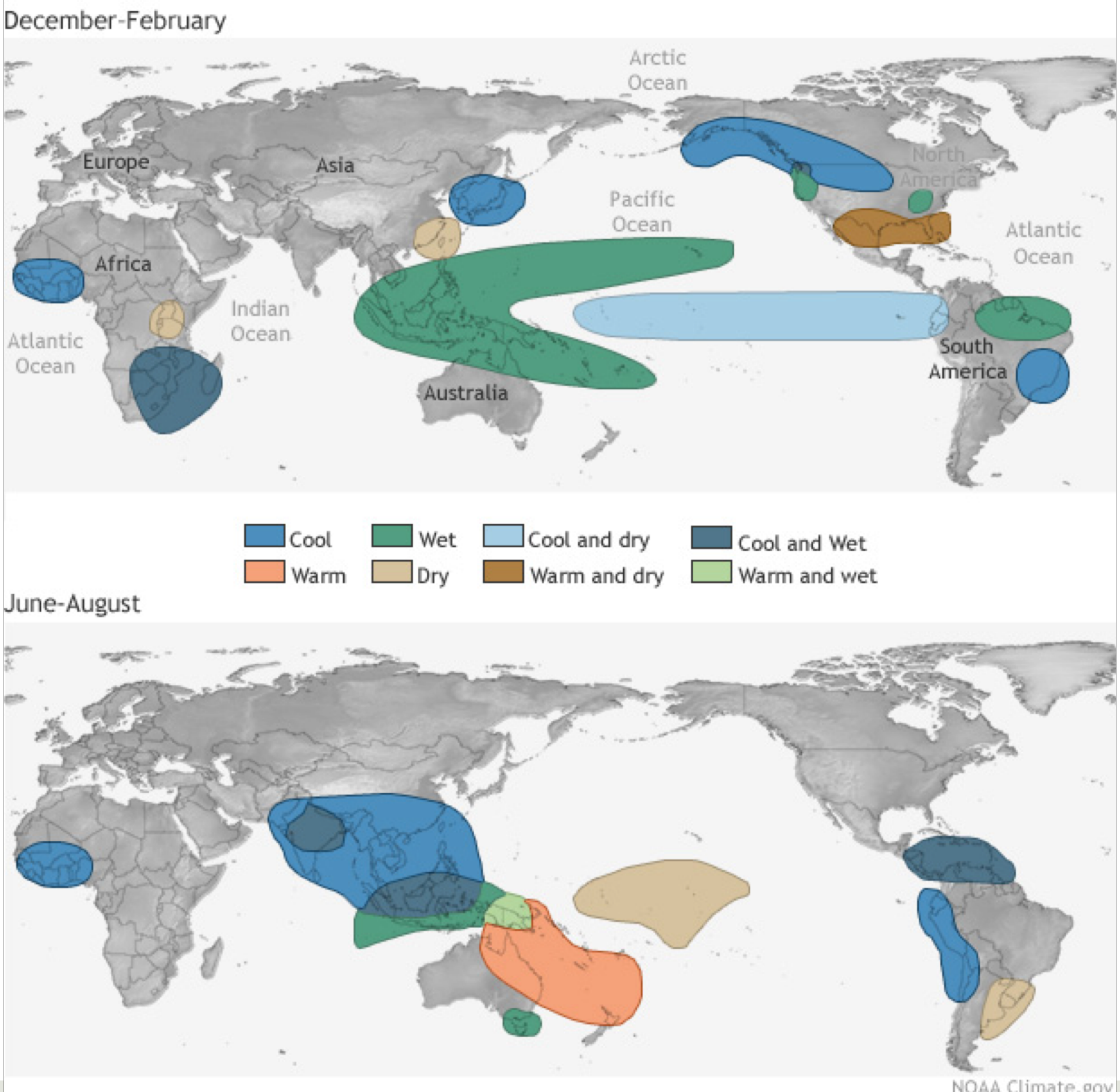


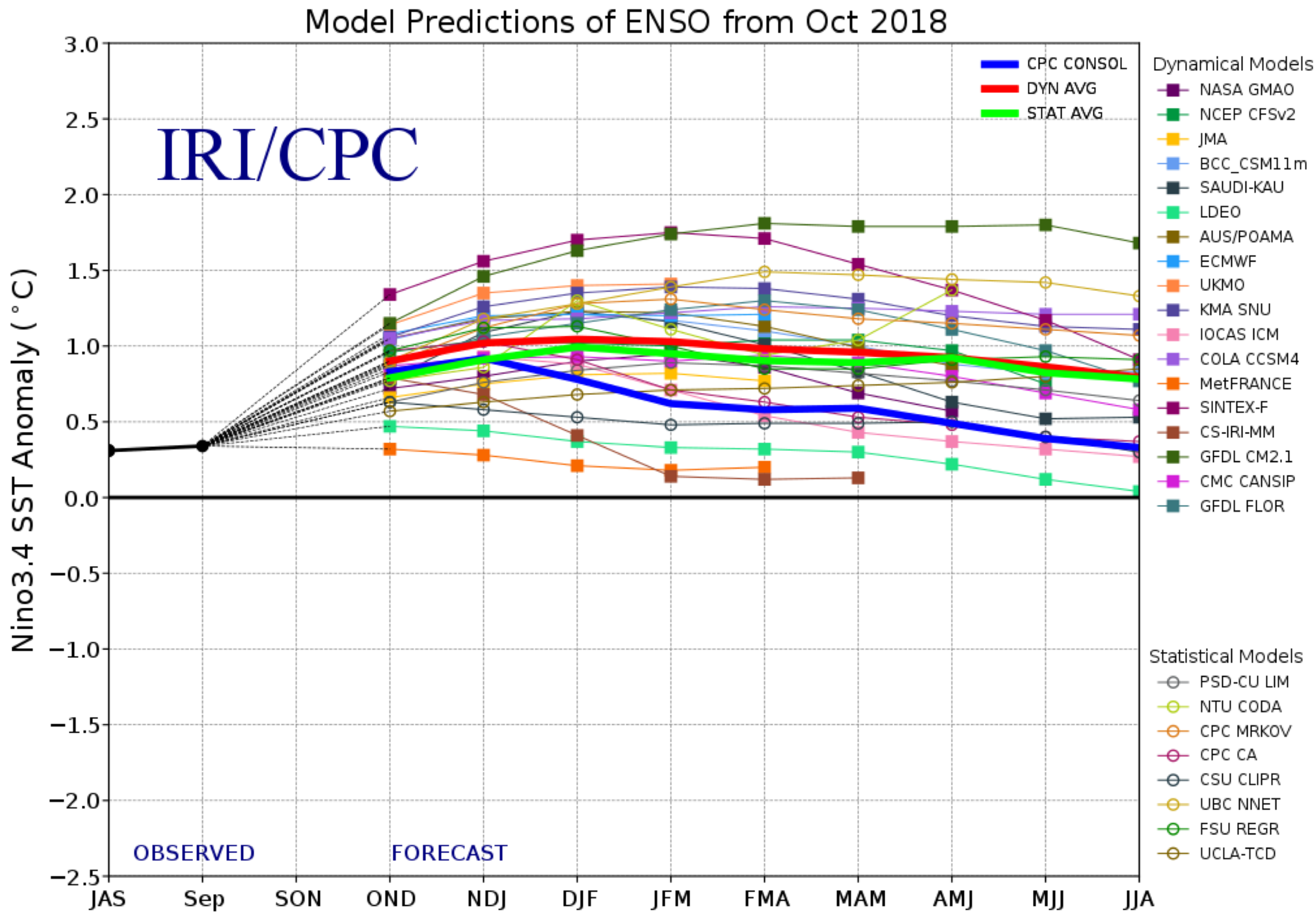
- **Climate Variability** is a measure of shorter term climate fluctuations above or below long term average
- **Climate Change** is a measure of longer term statistically significant continuous change (increase or decrease) in the measures of climate, such as temperature, rainfall, frequency of extreme events

EL NIÑO CLIMATE IMPACTS

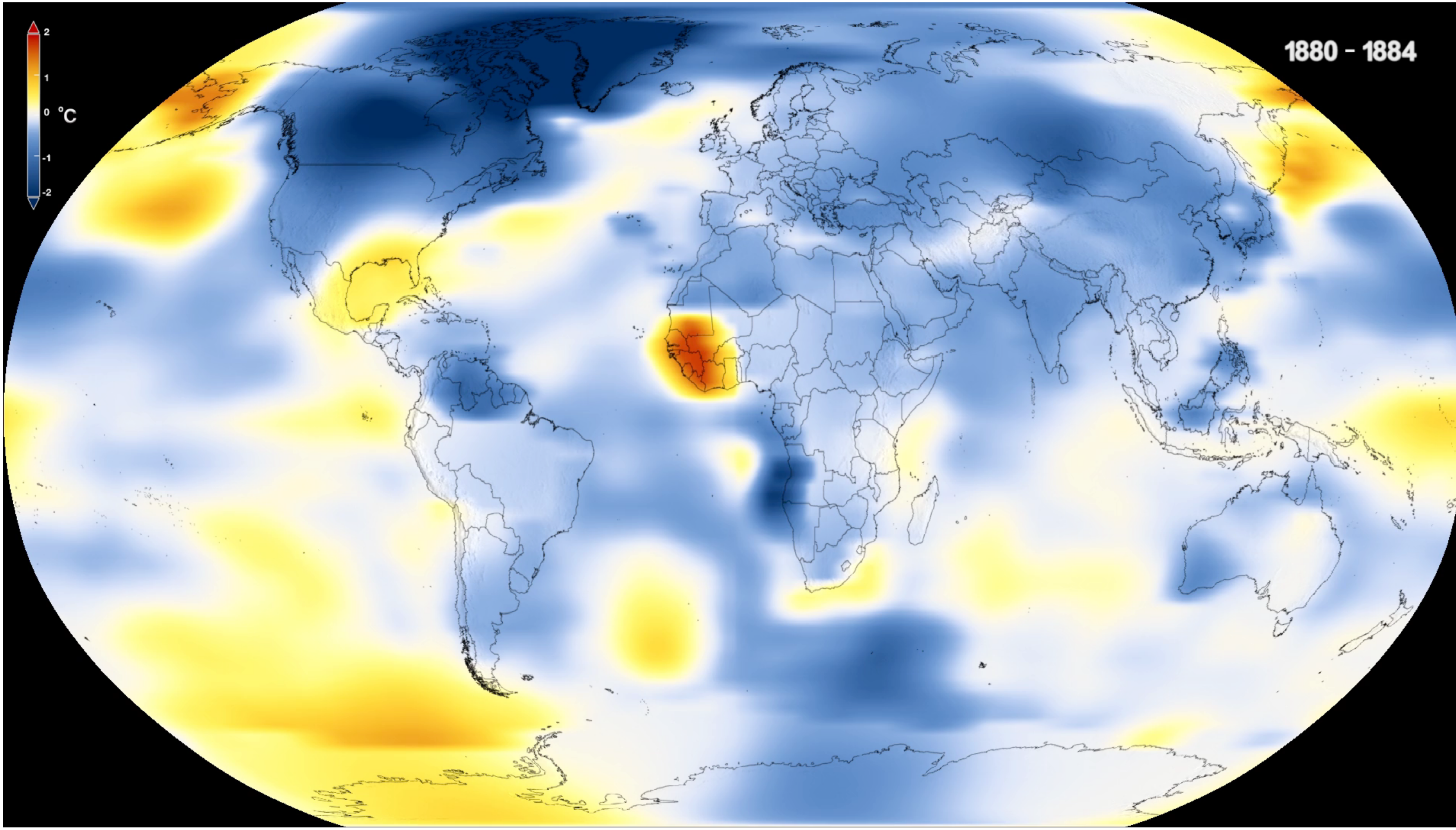


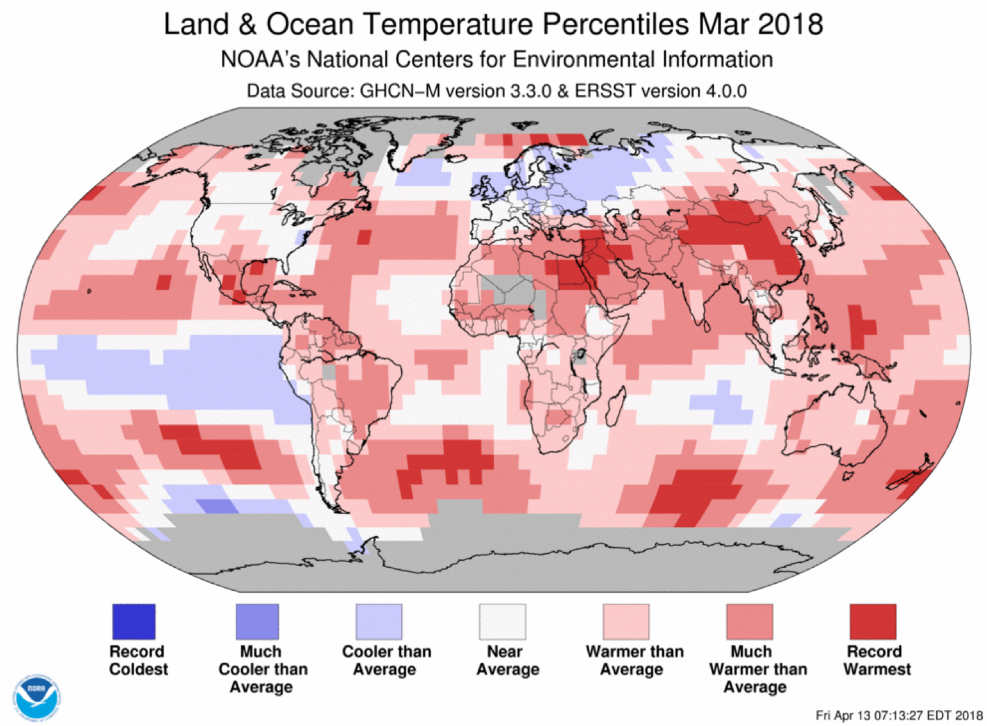
LA NIÑA CLIMATE IMPACTS

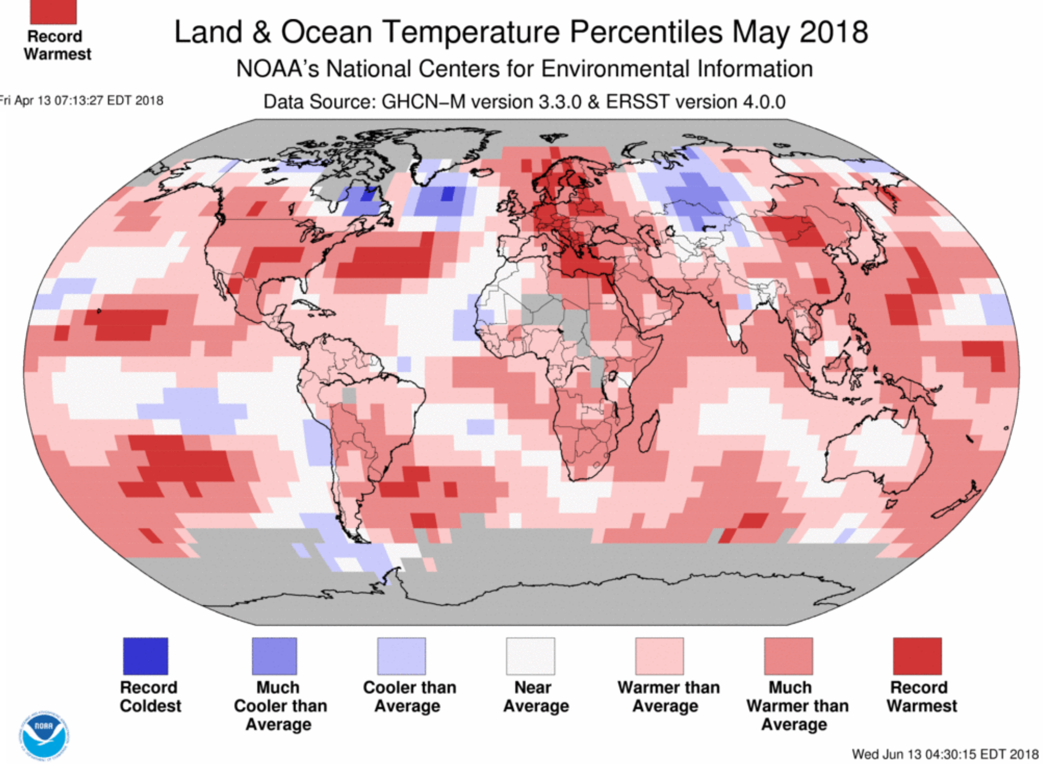




Model Predictions of ENSO from Oct 2018
IRI/CPC
Nino3.4 SST Anomaly (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
JAS
Sep
SON
OND
NDJ
DJF
JFM
FMA
MAM
AMJ
MJJ
JJA
OBSERVED
FORECAST
CPC CONSOL
DYN AVG
STAT AVG
Dynamical Models
NASA GMAO
NCEP CFSv2
JMA
BCC_CSM11m
SAUDI-KAU
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
IOCAS ICM
COLA CCSM4
MetFRANCE
SINTEX-F
CS-IRI-MM
GFDL CM2.1
CMC CANSIP
GFDL FLOR
Statistical Models
PSD-CU LIM
NTU CODA
CPC MRKOV
CPC CA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD


2
1
0
°C
-1
-2
1880 - 1884


Land & Ocean Temperature Percentiles Mar 2018
NOAA's National Centers for Environmental Information
Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0
Record Coldest
Much Cooler than Average
Cooler than Average
Near Average
Warmer than Average
Much Warmer than Average
Record Warmest
Fri Apr 13 07:13:27 EDT 2018


Land & Ocean Temperature Percentiles May 2018
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Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0
Record Coldest
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Record Warmest
Wed Jun 13 04:30:15 EDT 2018

Changes in California Temperatures

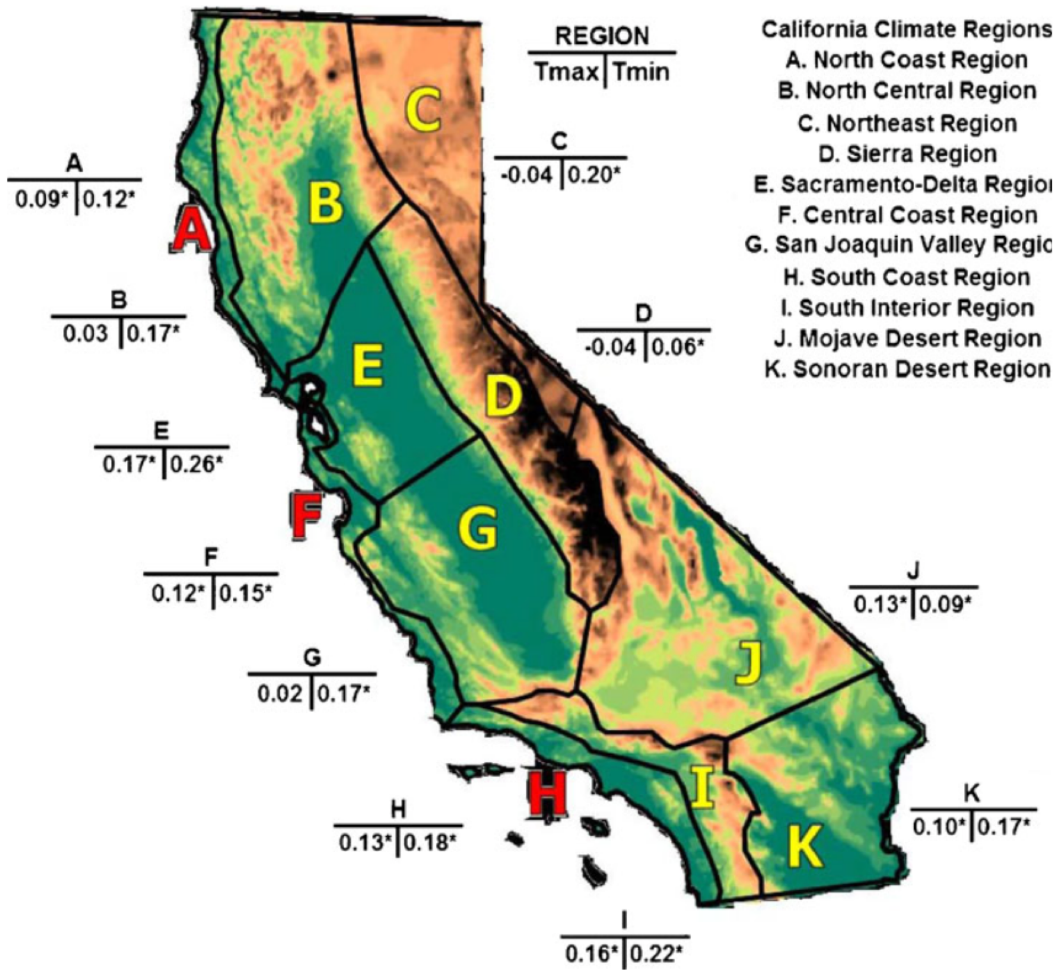
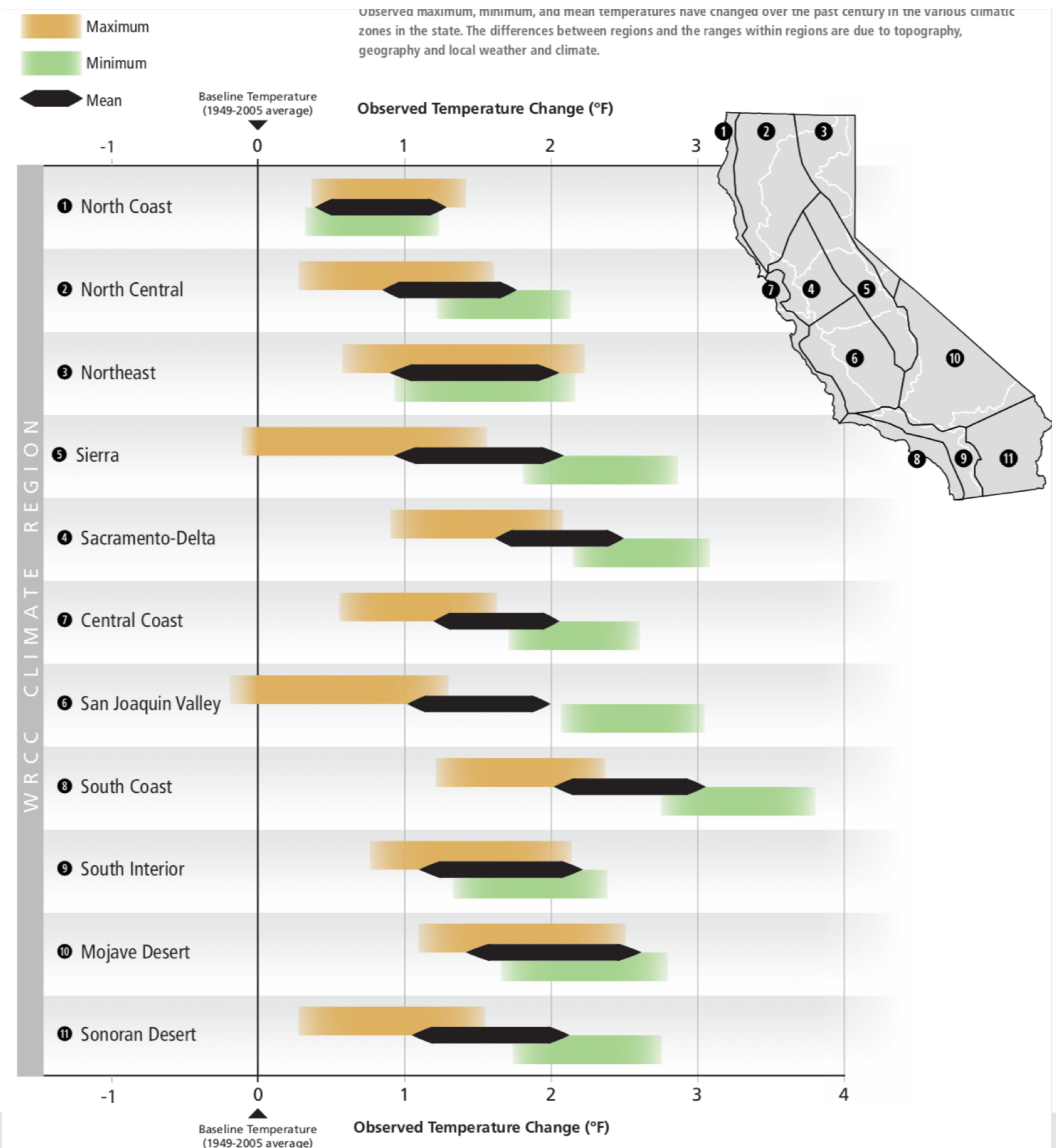


Fig. 4 Annual temperature trends (°C dec^{-1}) for the 11 climate regions labeled *A-K* computed between 1918–2006 for Tmax (*left*) and Tmin (*right*), where the trends that are statistically significant at the 95% confidence level are indicated with an *asterisk*

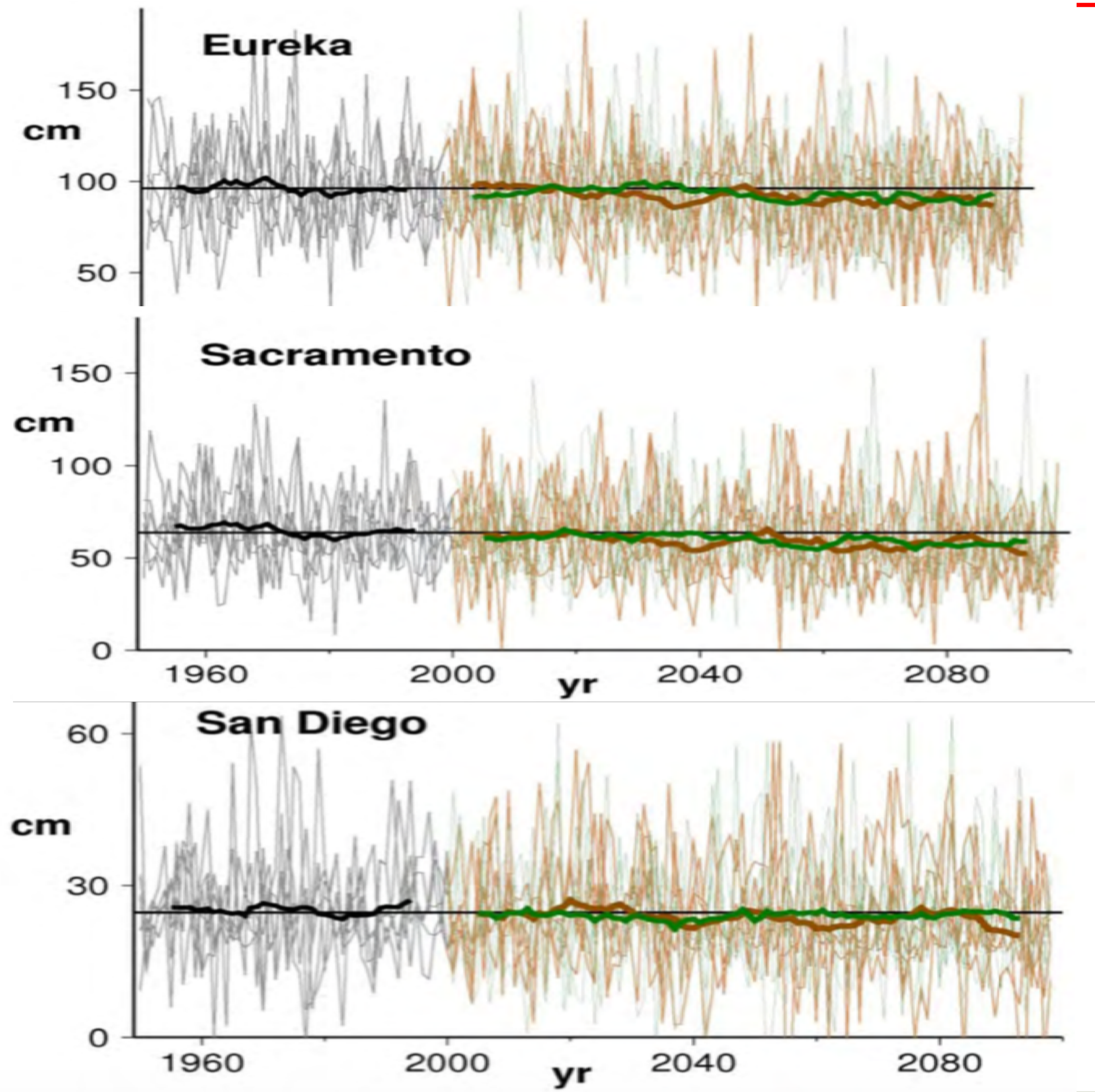
Cordero et al. (2011)

Changes in California Temperatures



CA DWR, 2015

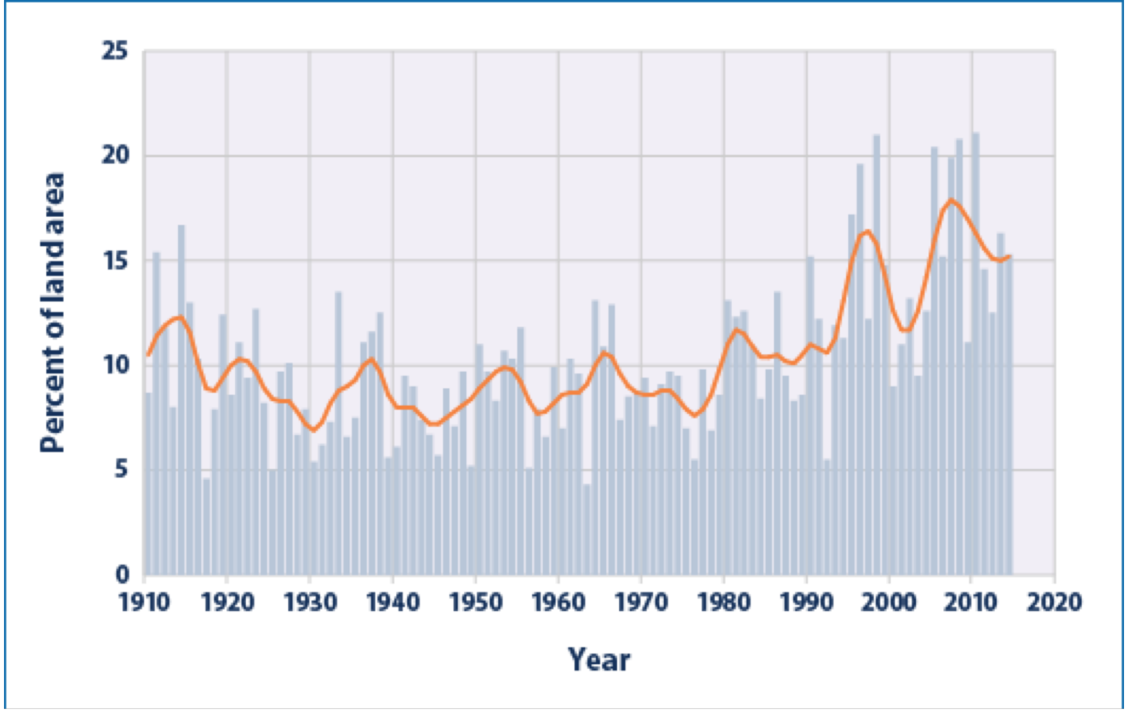
Precipitation Trends



- No clear trend in precipitation
- Large amount of variability, not only from month to month but from year to year and decade to decade suggesting California will remain vulnerable to drought and flooding

Extreme One-Day Precipitation Indicators

Figure 1. Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2014



- Eight of the top 10 years for extreme one-day precipitation events have occurred since 1990
- Number of extreme one-day precipitation events have increased substantially from 1980 onwards

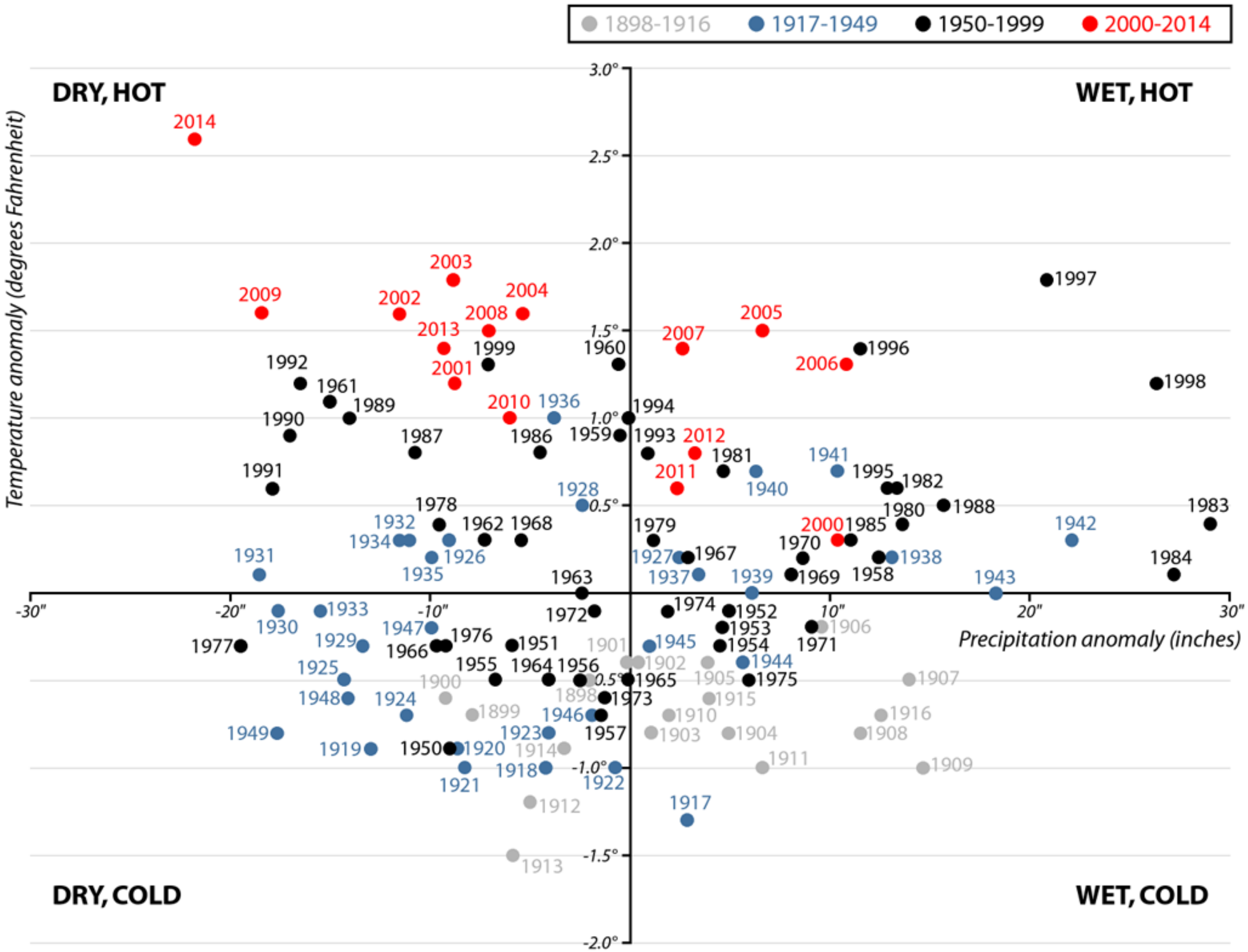
Source: EPA

Hot, Dry Years Becoming More Common in California

California recently emerged from a five-year drought, but data show the state has been slowly shifting over the past century toward hotter, drier years.

CALIFORNIA TEMPERATURE AND PRECIPITATION ANOMALIES

Deviations from 1901-2000 mean, 1898-2014



SOURCE: M. Mann and P. Gleick, PNAS, 2017

PAUL HORN / InsideClimate News

Number of Extreme Heat Days

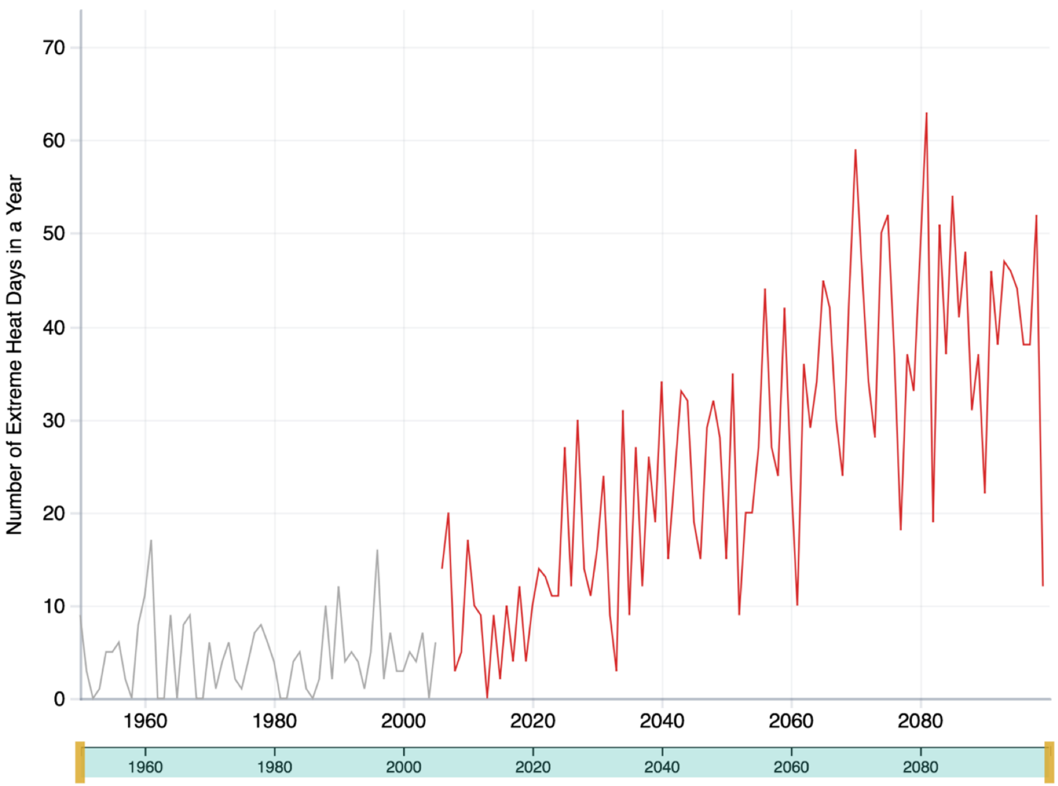
GRID CELL (37.34375, -120.46875)

Emissions peak around 2040, then decline (RCP 4.5)

Observed Data (1950–2005)

Modeled Data (2006–2099)

HadGEM2-ES



SCENARIOS

RCP 4.5

Emissions peak around 2040, then decline

RCP 8.5

Emissions continue to rise strongly through 2050 and plateau around 2100

QUICK STATS

Extreme Heat Threshold

104.1°F

Average number of days with high above 104.1°F in 1961–1990

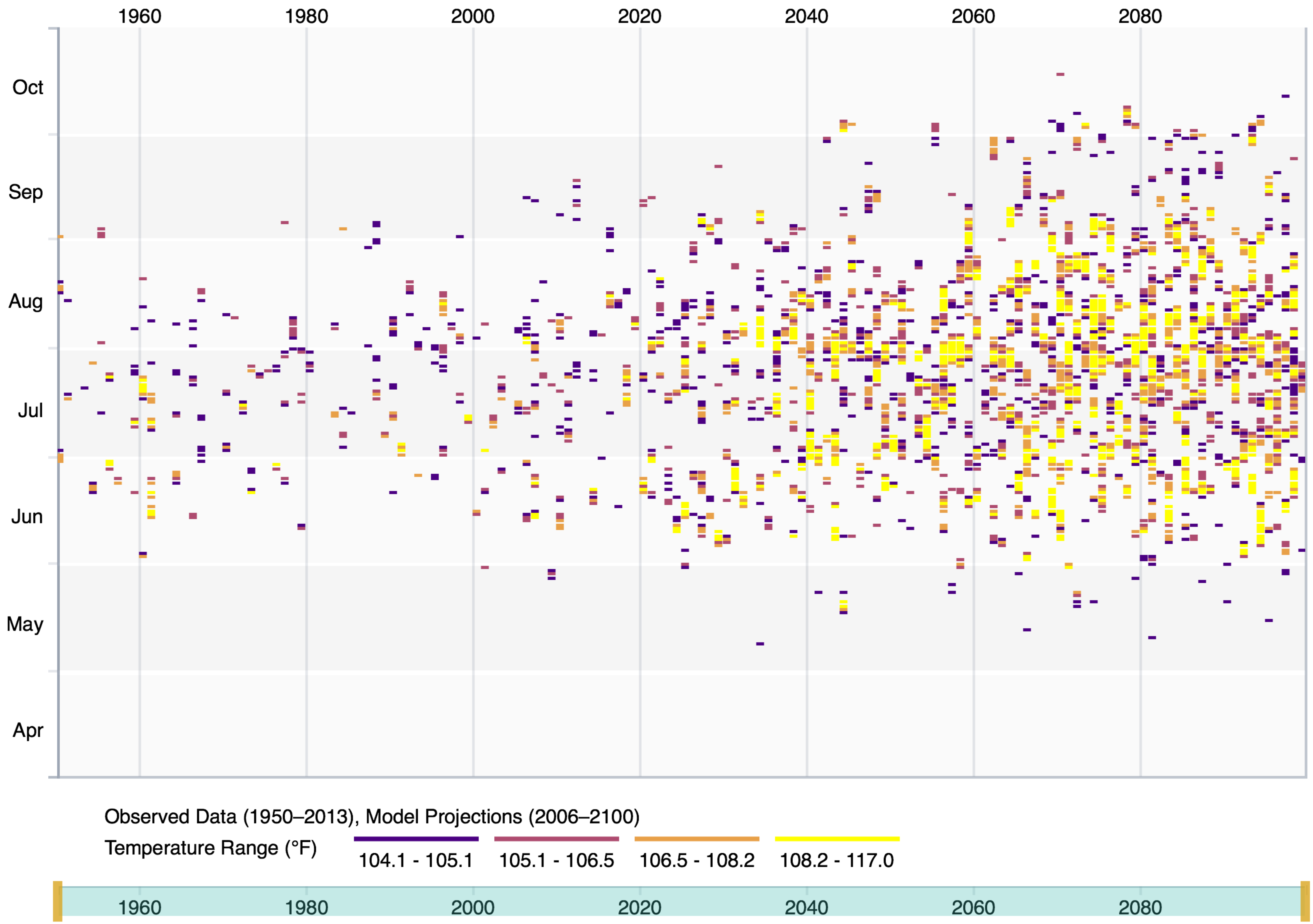
4.3

Average number of days with high above 104.1°F in 2070–2099

40

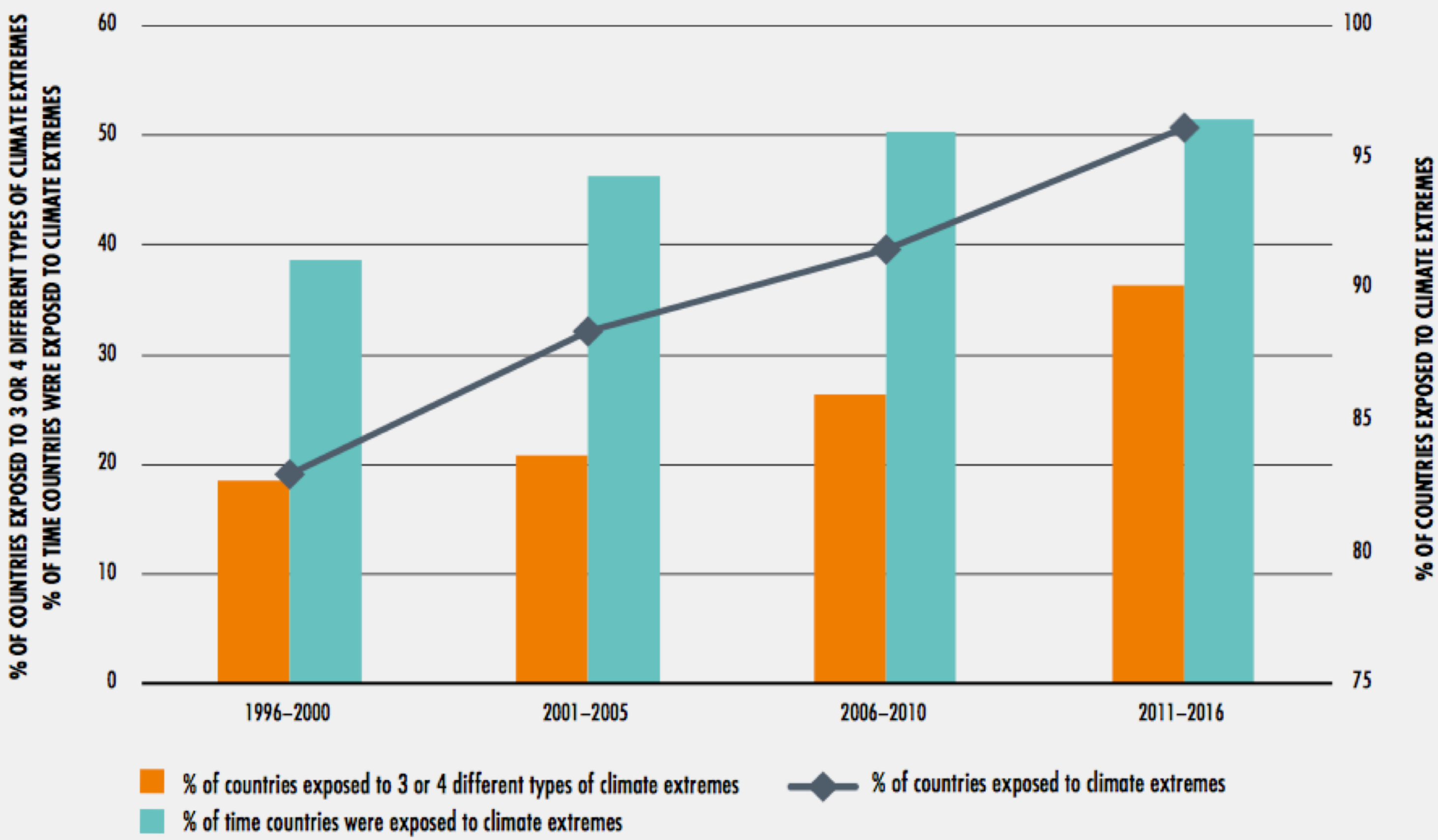
Reference: cal-adapt.org

Timing of Extreme Heat Days



Reference: cal-adapt.org

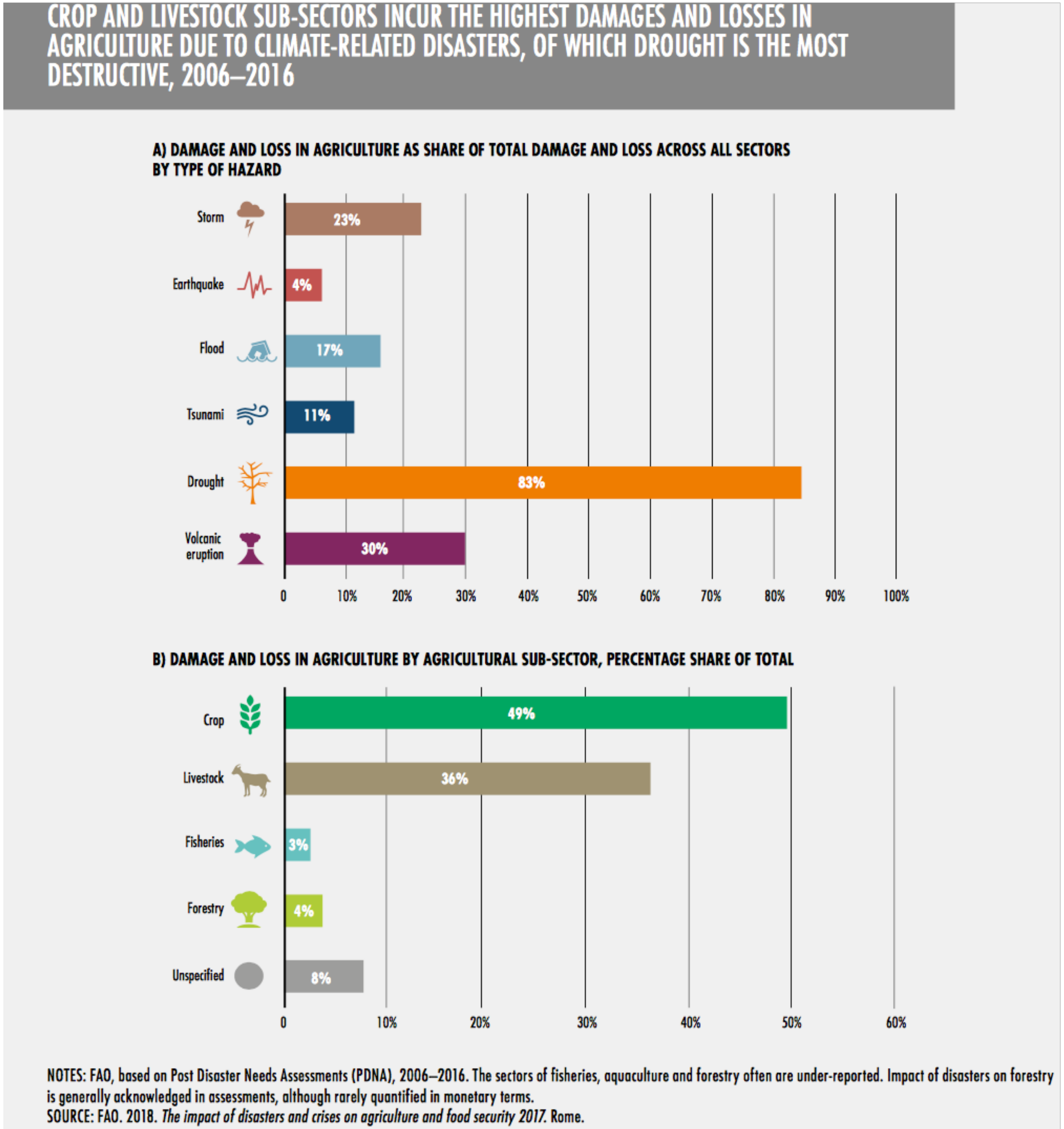
INCREASED EXPOSURE TO MORE FREQUENT AND MULTIPLE TYPES OF CLIMATE EXTREMES IN LOW- AND MIDDLE-INCOME COUNTRIES



NOTES: Percentage of low- and middle-income countries exposed to three or four types of climate extremes (extreme heat, drought, floods and storms) during any of the periods shown; percentage of time (based on the average number of years within a period) that a country was exposed to climate extremes; and percentage of countries exposed to at least one climate extreme in each period. Results are presented using five-year periods, except for 2011–2016 which is a six-year period. See Annex 2 for definition and methodology. Analysis is only for low- and middle-income countries.

SOURCE: C. Holleman, F. Rembold and O. Crespo (forthcoming). *The impact of climate variability and extremes on agriculture and food security: an analysis of the evidence and case studies*. FAO Agricultural Development Economics Technical Study 4. Rome, FAO.

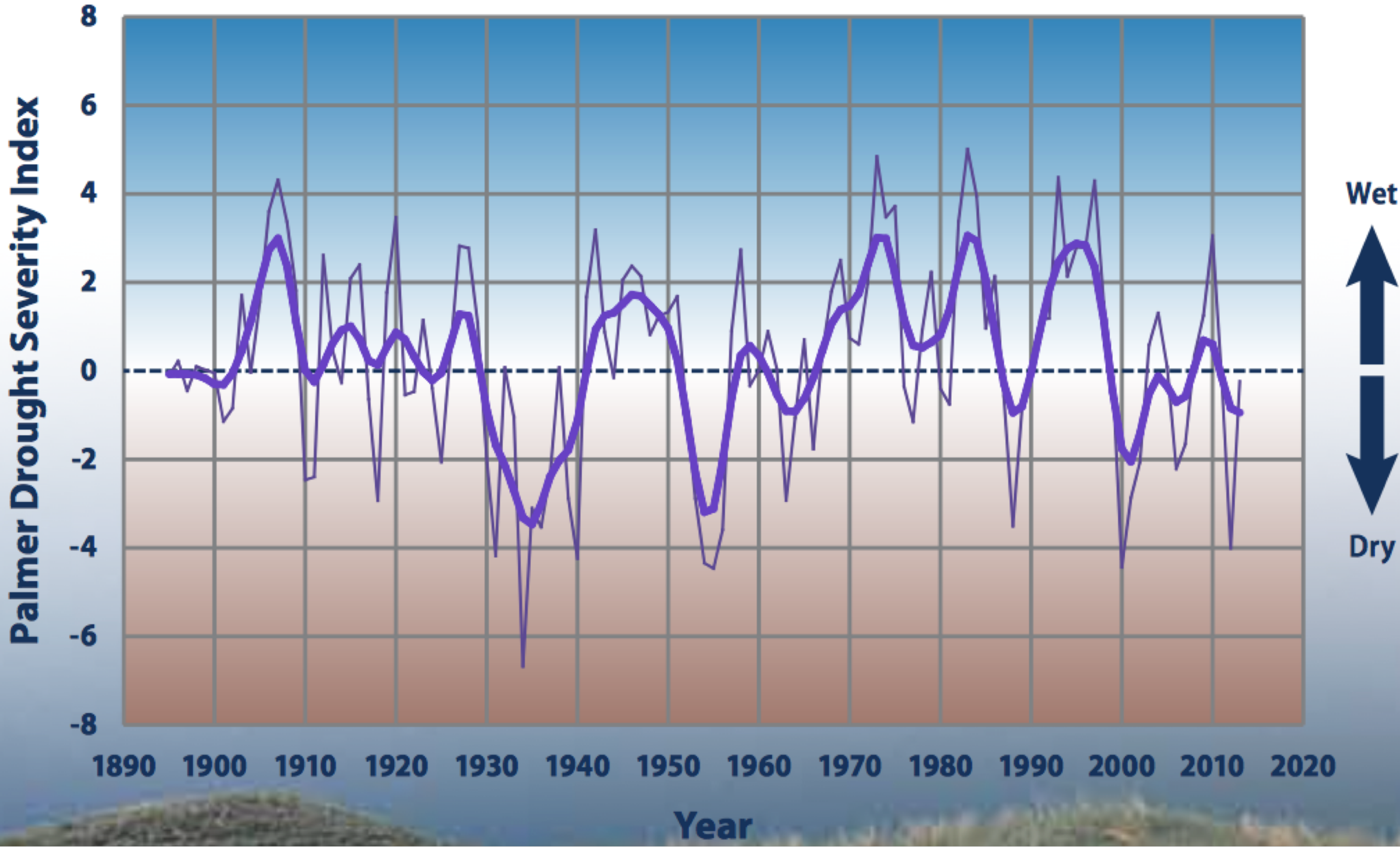
Ref: http://www.fao.org/state-of-food-security-nutrition/en/



Ref: http://www.fao.org/state-of-food-security-nutrition/en/

Drought

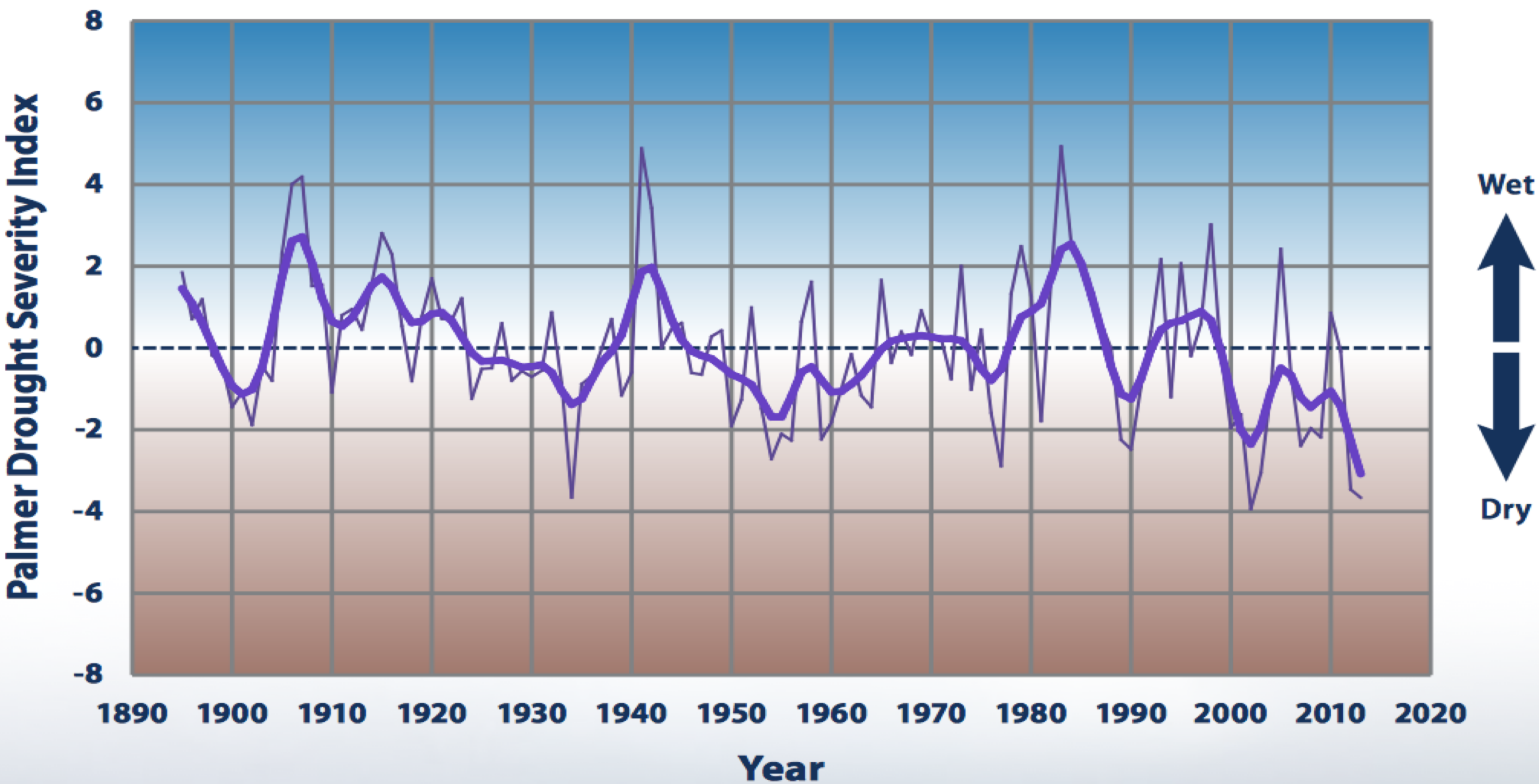
Figure 1. Average Drought Conditions in the Contiguous 48 States, 1895–2013



Source: EPA

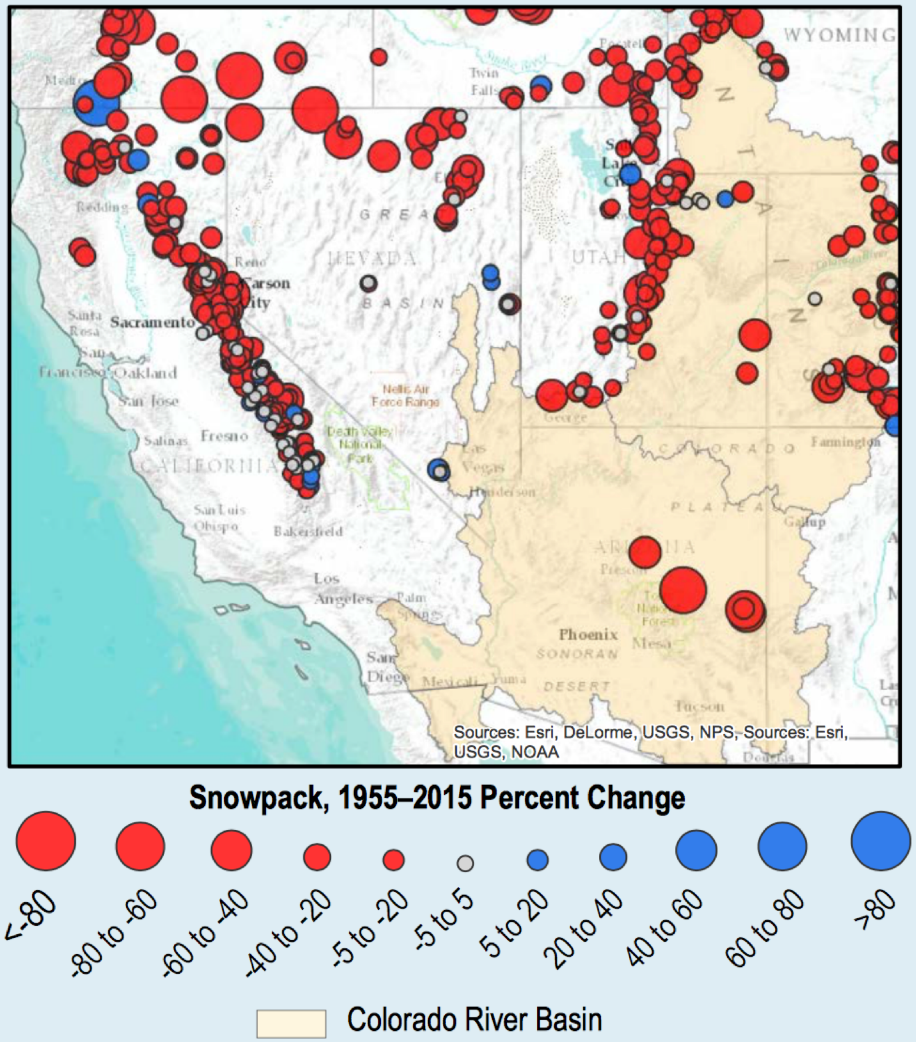
Drought

Figure 3. Drought Severity in the Southwestern United States, 1895–2013



Source: EPA

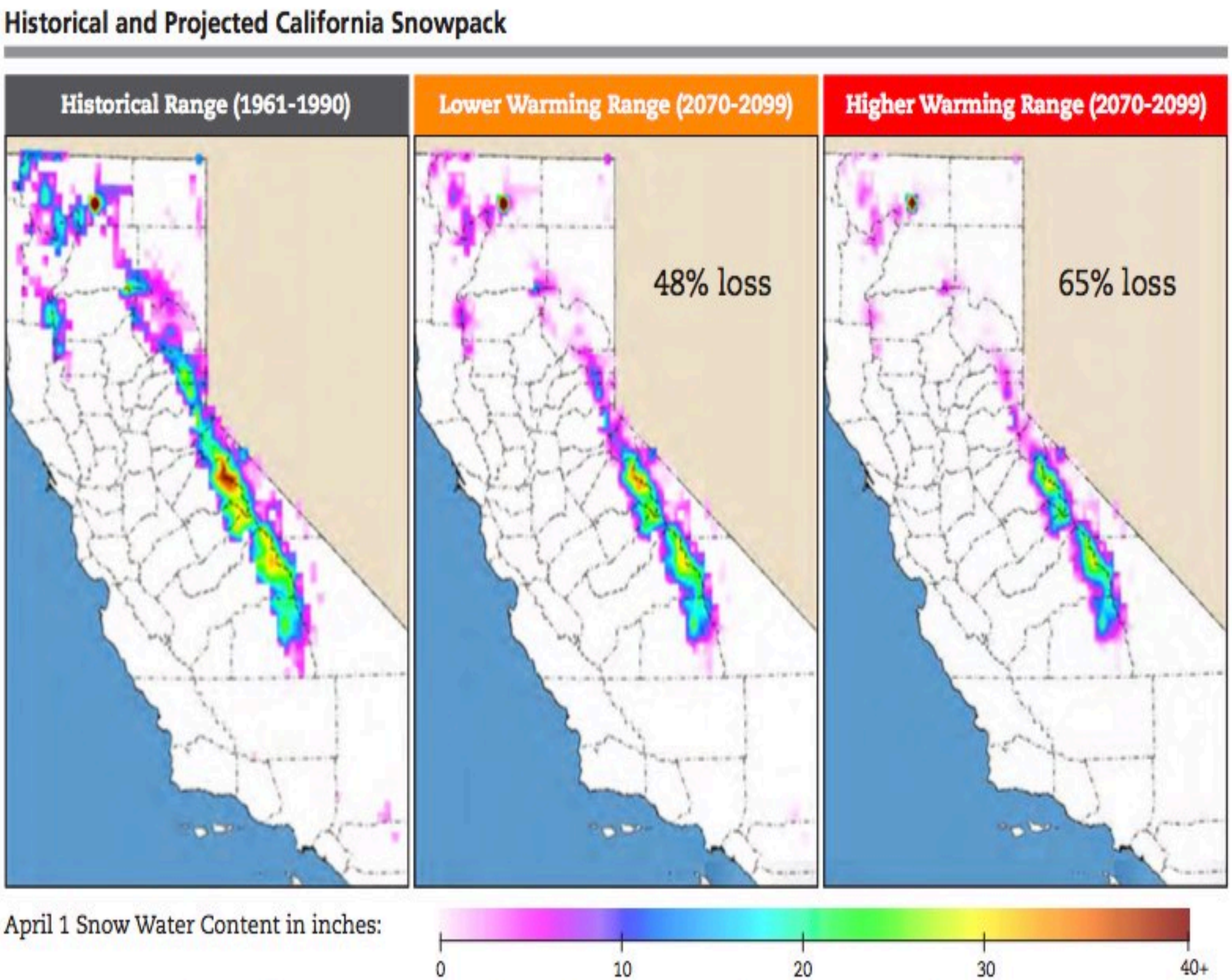
Snowpack



Trends in April snowpack in California and the Colorado River Basin, 1955–2013. Snowpack has decreased at most monitoring sites in California and the basin. Source: EPA.

Source: EPA

Snowpack



Source: CA DWR

- A loss of 48% and 65% of the snowpack is projected under low and high emission scenarios, respectively
- By 2081–2100, average temperatures in the Sierra Nevada are projected to increase by about 7–10 degrees F (UCLA study)

Impacts – Agriculture

Crop Sensitivity

- **Vegetables**: exposure to temperatures in the range of 1.8°F to 7.2°F above optimal moderately reduces yield. exposure to temperatures more than 9°F to 12.6°F above optimal often leads to severe if not total production losses
- **Perennial specialty crops**: Yields decline if the chilling requirement is not completely satisfied, because flower emergence and viability is low
- **Soybean and Alfalfa**: Elevated CO2 has been associated with reduced nitrogen and protein content
- **Corn**: high nighttime temperatures, high temperatures during pollination negatively impacts yield
- **Rice**: Temperature extreme during pollination
- **Cotton**: Higher temperature during boll filling stage

Calories consumed by food insecure population

Table S1) Average crop contribution to total calories consumed by food insecure populations. This was computed by multiplying the number of malnourished in each country by the percent contribution of the crop to total consumed calories in that country, and then summing these values for the entire world (left), Sub-Saharan Africa (middle), or South Asia (right). All data was obtained from the FAO (http://faostat.fao.org).

	World			Sub-Saharan Africa			South Asia		
Rank	Crop	% of Total Calories	Cumulative %	Crop	% of Total Calories	Cumulative %	Crop	% of Total Calories	Cumulative %
1	rice	28.6%	28.6%	cassava	18.0%	18.0%	rice	29.6%	29.6%
2	wheat	18.7%	47.3%	maize	17.0%	35.0%	wheat	23.9%	53.5%
3	sugar cane	9.2%	56.5%	wheat	8.0%	43.0%	sugar cane	15.1%	68.6%
4	maize	7.3%	63.8%	sorghum	8.0%	51.0%	palm nuts	3.7%	72.3%
5	cassava	4.8%	68.6%	rice	6.0%	57.0%	millet	3.1%	75.4%
6	palm nuts	3.0%	71.6%	millet	4.0%	61.0%	groundnuts	2.3%	77.7%
7	soybeans	2.9%	74.5%	sugarcane	4.0%	65.0%	maize	2.3%	80.0%
8	sorghum	2.5%	77.0%	groundnuts	4.0%	69.0%	sorghum	2.1%	82.1%
9	groundnuts	2.4%	79.4%	palm nuts	4.0%	73.0%	soybeans	1.8%	83.9%
10	millet	2.0%	81.4%	beans	3.0%	76.0%	rapeseed	1.7%	85.6%
11	potatoes	2.0%	83.4%	plantains	2.0%	78.0%	chickpeas	1.7%	87.3%
12	beans and cowpeas	1.3%	84.7%	cereals nec	2.0%	80.0%	potatoes	1.6%	88.9%
13	sweet potatoes	1.2%	85.9%	sweet potatoes	2.0%	82.0%	pulses	1.3%	90.2%
14	barley	1.0%	86.9%	barley	2.0%	84.0%	coconuts	1.1%	91.3%
15	rapeseed	0.9%	87.8%	yams	2.0%	86.0%	beans and cowpeas	0.9%	92.2%

Reference: Lobell et al., 2008

Sensitivity to temperature increases

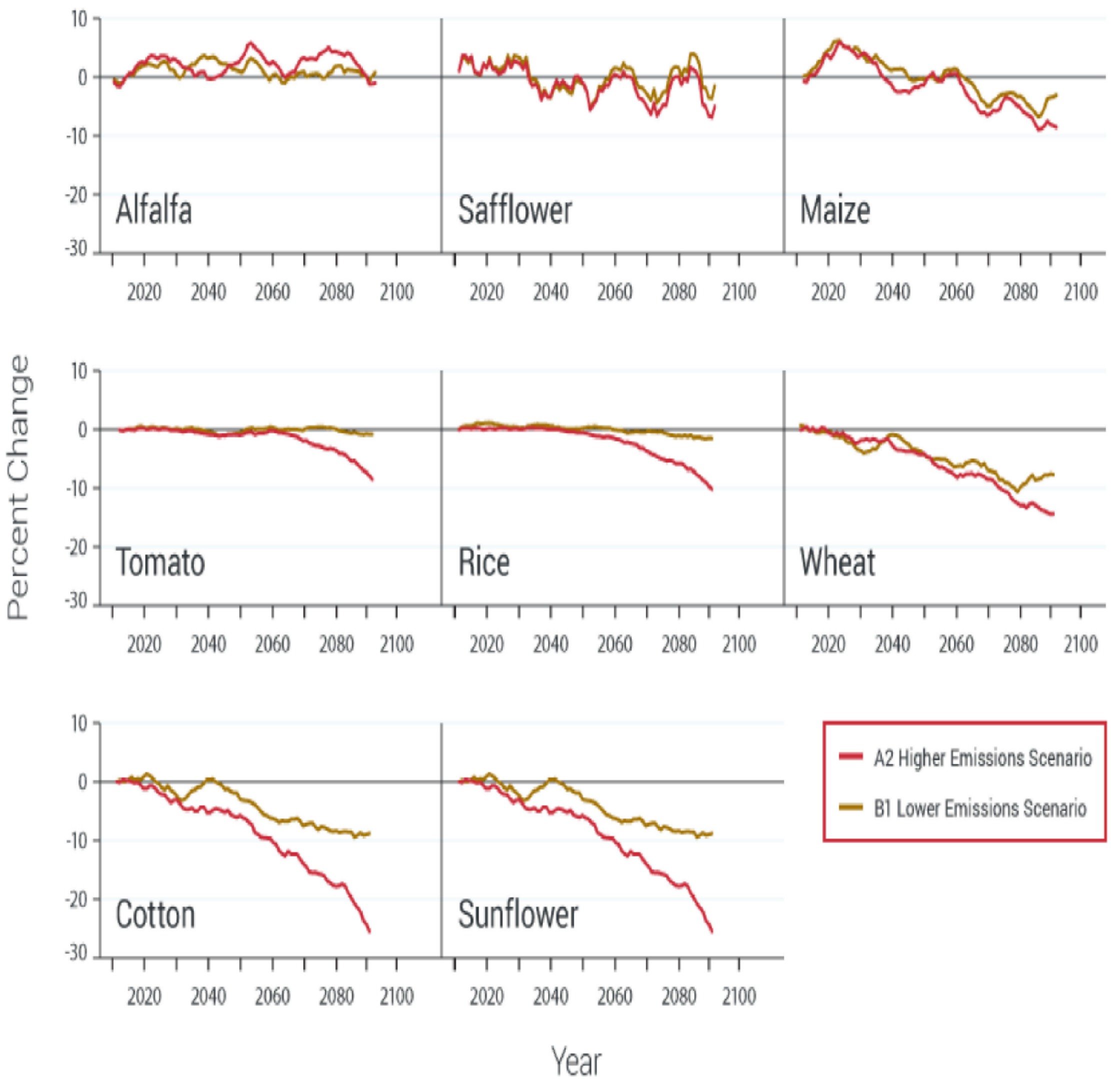
Table S3. Comparison of estimated crop sensitivities to 1.0 ºC temperature increase in the current study and in previous modeling studies.

Region	Crop	%Yield Change per 1.0 ºC, current study [a]	Reference	Model Used	Location	%Yield Change per 1.0 ºC [b]
South Asia	Rice	-4.0 ± 2.0	(S24)	CERES-Rice	NW India	-10
			(S25)	CERES-Rice	India	-6
			(S26)	CERES-Rice	India	-10 - -2.5
	Wheat	-2.6 ± 0.7	(S24)	CERES-Wheat	NW India	-13
			(S27)	CERES-Wheat	NW India	-9 – -3
			(S28)	CERES-Wheat	Pakistan	-17 - -7
			(S29)	CERES-Wheat	India	-15
	Maize	-4.8 ± 3.7	(S30)	CERES-Maize	India	-8
Southeast Asia	Rice	-1.4 ± 0.8	(S31)	CERES-Rice	Bangladesh	-9 - -4
			(S32)	CERES-Rice	Philippines	-14 - -8
			(S33)	CERES-Rice	Thailand	-14 - -12
Southern Africa	Maize	-21.4 ± 8.6	(S34)	CERES-Maize	Zimbabwe	-7 - -4
Central America	Wheat	-5.1 ± 1.8	(S22)	CERES-Wheat	NW Mexico	-12 - -7
	Maize	-0.6 ± 1.9	(S35)	CERES-Maize	Mexico	-5
Brazil	Wheat	-7.1 ± 2.4	(S36)	CERES-Wheat	Brazil	-16 - -9
	Maize	-2.4 ± 2.5	(S36)	CERES-Maize	Brazil	-8 - -4
	Soybean	-4.5 ± 3.9	(S36)	SOYGRO	Brazil	-6 - +3

[a] coefficient for temperature in yield regression model (mean ± 1 standard deviation)
[b] range shows values for different sites or management levels, when available

Reference: Lobell et al., 2008

Impacts on Yield



Expected yield reductions by 2097: cotton (≈ 29%) > sunflower (≈ 26%) > wheat (≈ 15%) > maize (12%) > rice (≈ 10%) > tomato (≈ 9%)

These yield decreases were mainly because high temperatures under climate change shorten the duration of phenological phases

Limitations related to water supply to irrigated croplands

Adaptation measures such as management practices and improved cultivars may alleviate some of the impacts

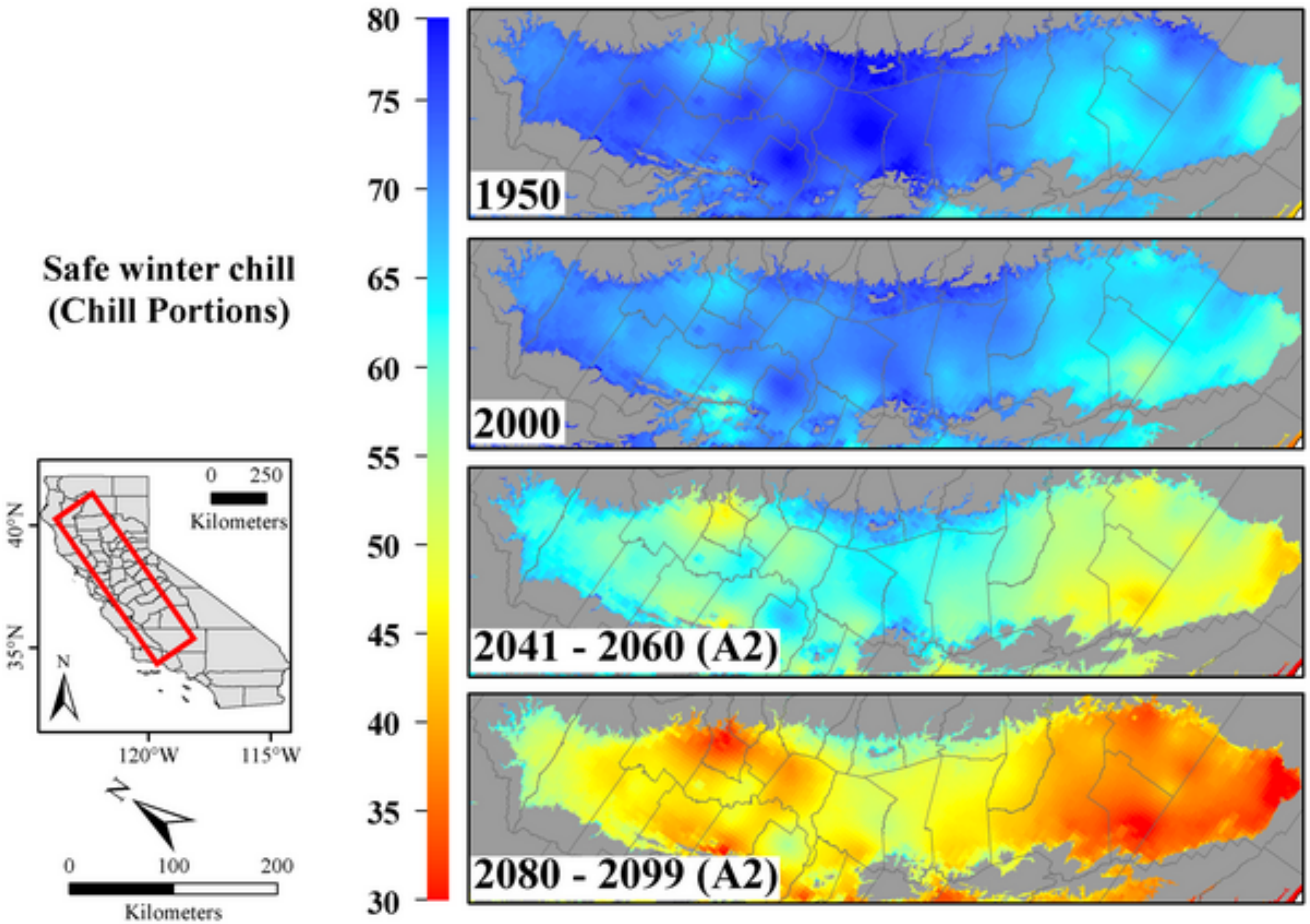
Impacts due to extreme temperature

Table 1. Total Vegetative biomass and grain weights for maize exposed to temperature extremes and soil water differences in a controlled environment chamber.

Chamber	Soil water treatment	Total vegetative dry matter (g m^{-2})	Grain yield (g m^{-2})
Normal temperature	Normal precipitation	3739.5	1573.5
Normal temperature	0.75 Normal precipitation	3000.7	707.0
Normal temperature	1.25 Normal precipitation	2708.1	944.1
Extreme temperature	Normal precipitation	1744.8	823.4
Extreme temperature	0.75 Normal precipitation	1282.6	805.6
Extreme temperature	1.25 Normal precipitation	1081.8	353.9

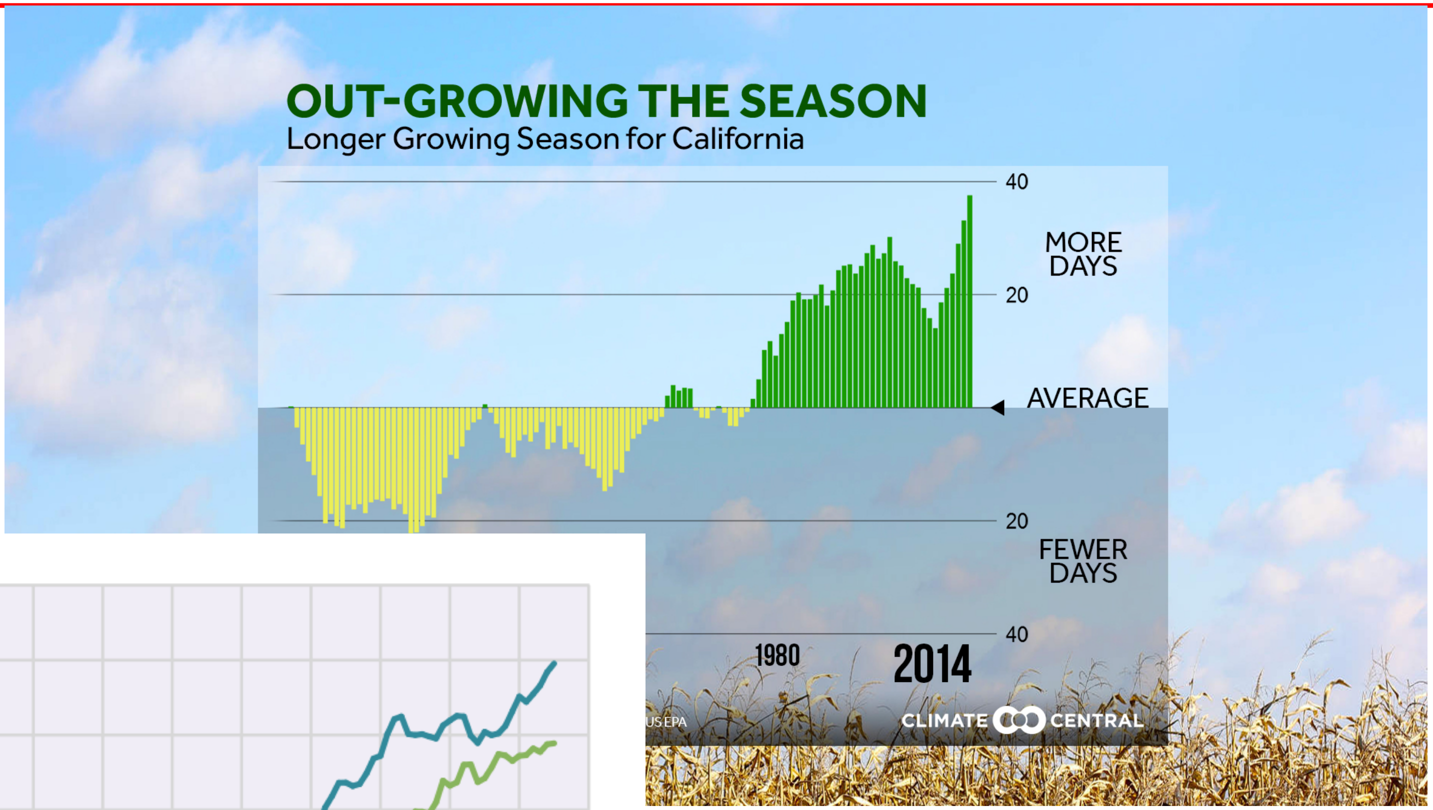
Hatfield and Prueger, 2015

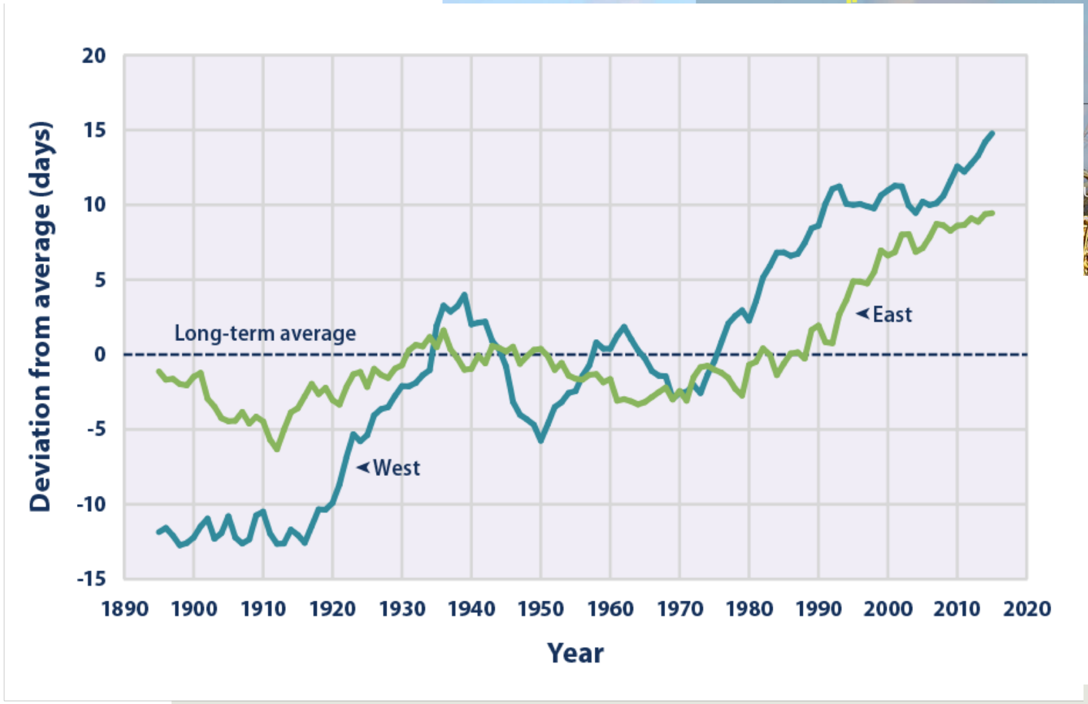
Trends in Chill Portions



Luedeling E, Zhang M, Girvetz EH (2009) Climatic Changes Lead to Declining Winter Chill for Fruit and Nut Trees in California during 1950–2099. PLoS ONE 4(7): e6166. doi:10.1371/journal.pone.0006166
http://journals.plos.org/plosone/article?id=info:doi/10.1371/journal.pone.0006166

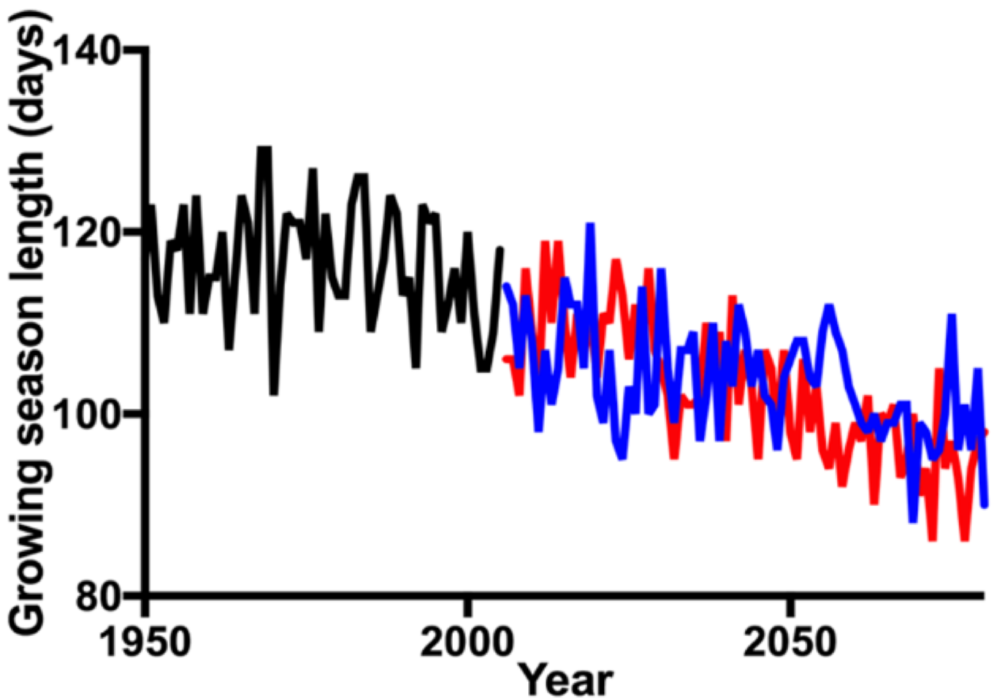
Length of Growing Season





Source: EPA

Impacts on Crop Growing Season



Pathak and Stoddard, 2018

Photo credit: California Tomato Growers Association

https://link.springer.com/article/10.1007/s40808-018-0460-y

Impacts due to Agricultural Pests and Diseases

TABLE 2. Examples of how increasing temperatures affect arthropod species and arthropod-related systems

Increasing atmospheric carbon dioxide leads to:	Reference
Increasing . . .	
Northward migration	Parmesan 2006
Migration up elevation gradients	Epstein et al. 1998
Insect developmental rates and oviposition	Regniere 1983
Potential for insect outbreaks	Bale et al. 2002
Invasive species introductions	Dukes and Mooney 1999
Insect extinctions	Thomas et al. 2004
Occurrence of human and animal diseases	Juliano and Lounibos 2005; Patz et al. 2003
Decreasing . . .	
Effectiveness of insect biocontrol by fungi	Stacy and Fellowes 2002
Reliability of economic threshold levels	Predicted in this paper
Insect diversity in ecosystems	Erasmus et al. 2002
Parasitism	Hance et al. 2007; Fleming and Volney 1995

Trumble and Butler, 2009

http://calag.ucanr.edu/Archive/?article=ca.v063n02p73

Summary

- Climate in California has changed significantly over the last century and this change is expected to continue in the future

- Observed and projected changes and potential impacts include but not limited to increased minimum and maximum temperatures, highly variable and shifting precipitation patterns, reduced amount of snowpack in the Sierras, and increased frequency and intensity of weather extremes such as heat waves, drought, and extreme precipitation events

- Agricultural impacts of climate change include but not limited reduced chill accumulations, crop yield declines, increased pest and disease pressure, increased crop water demands, altered phenology of annual and perennial cropping systems, and uncertain future sustainability of some highly vulnerable crops

- Improving resilience to climate change requires protection of natural resources and development of new research relevant to the stakeholders needs. We need to play proactive role towards climate change solutions and effective climate communication

Potential Research Needs

- Enhanced understanding of agricultural impacts of potential exposures to extreme events and other climate risks
- Need more localized innovative research and development of decision tools that integrate scientific, social, and economic factors for effective adoption of new innovations
- Need for parameterization and validation of models to be utilized for optimizing crop performance under limited water supply and future climate scenarios
- Increase skills in forecasting extreme precipitation events and better linkage with optimizing water storage and flood protection
- Increased research efforts on expanding adaptation to water shortages in agriculture
- Simply providing the scientific facts is inefficient. Solutions need to integrate stakeholder challenges and help them translate the science into actionable strategies

Thank You!

Contact Information

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