“Insights from the climate modeling community with special attention to High Resolution Modeling”

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Creating Practical Solutions for People and the Planet

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SCHOOL OF EARTH SCIENCES

NASA

USGS
science for a changing world

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DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

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Author Lists

- Diffenbaugh, N.S. and M. Scherer, in prep
- Diffenbaugh, N.S., M. Ashfaq and M. Scherer, *JGR*, in review
- Giorgi, F., E. Coppola, E.S. Im, N.S. Diffenbaugh, X. Gao and Y. Shi, *Journal of Climate*, in press
- Diffenbaugh, N.S. and M. Scherer, Climatic Change Letters, 2011
- Diffenbaugh, N.S., M.A. White, G.V. Jones and M. Ashfaq, *Environmental Research Letters*, 2011
- Diffenbaugh, N.S., and M. Ashfaq, *GRL,* 2010
- Walker, M.D. and N.S. Diffenbaugh, *Climate Dynamics,* 2009
- Rauscher, S.A., J.S. Pal, N.S. Diffenbaugh and M. Benedetti, *Geophysical Research Letters*, 2008
- Diffenbaugh, N.S., C.H. Krupke, M.A. White and C.E. Alexander, *Environmental Research Letters*, 2008
- Diffenbaugh, N.S., J.S. Pal, F. Giorgi and X. Gao, *Geophysical Research Letters*, 2007
- White, M.A., N.S. Diffenbaugh, G.V. Jones, J.S. Pal and F. Giorgi, *PNAS,* 2006

Objective:

Motivate some climate-related issues that could pose challenges for the energy-land-water nexus and may (or may not) be integratable into the Integrated Assessment Model framework

Climate and the Energy-Land-Water Nexus

Climate change can influence the need for and availability of:

- Energy
- Land
- Water

for a variety of sources and uses

Some Questions

- What processes determine the response of climate to changes in radiative forcing?

- How might natural and human systems be affected?

- How do climate processes and impacts respond to different interventions?

(“changes in radiative forcing” - e.g., changes in global greenhouse gas concentrations)

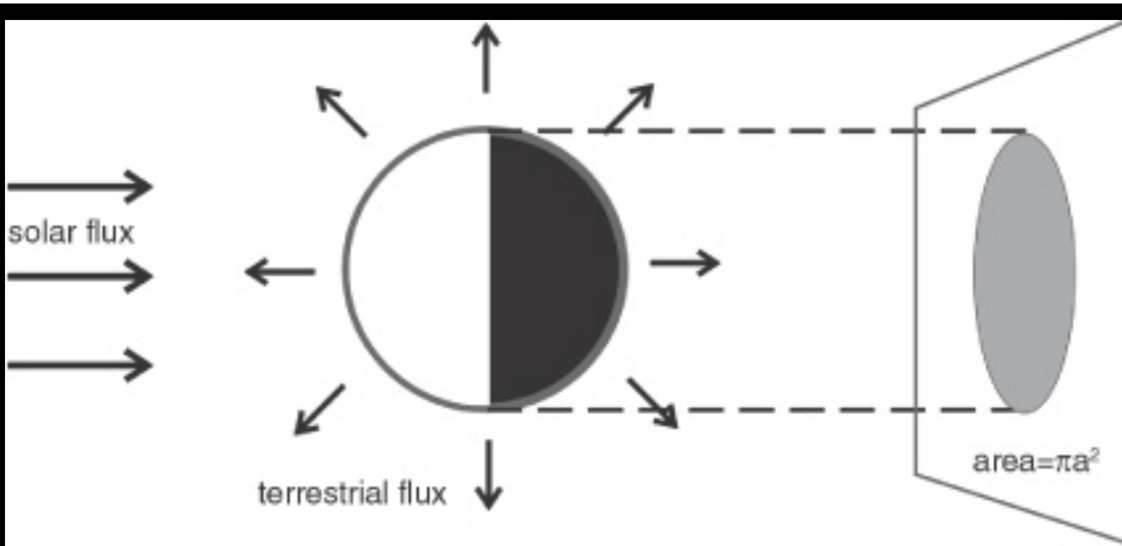


Figure 2.4: The spinning Earth is imagined to intercept solar energy over a disk of radius a and radiate terrestrial energy away isotropically from the sphere.

(Modified from Hartmann, 1994.)

From Marshall and Plumb, Elsevier, 2008

TABLE 2.1. Properties of some of the planets. S_0 is the solar constant at a distance r from the Sun, α_p is the planetary albedo, T_e is the emission temperature computed from Eq. 2 4, T_m is the measured emission temperature, and T_s is the global mean surface temperature. The rotation period, τ, is given in Earth days.

	r 10^9 m	S_0 W m^{-2}	α_p	T_e K	T_m K	T_s K	τ Earth days
Venus	108	2632	0.77	227	230	760	243
Earth	150	1367	0.30	255	250	288	1.00
Mars	228	589	0.24	211	220	230	1.03
Jupiter	780	51	0.51	103	130	134	0.41

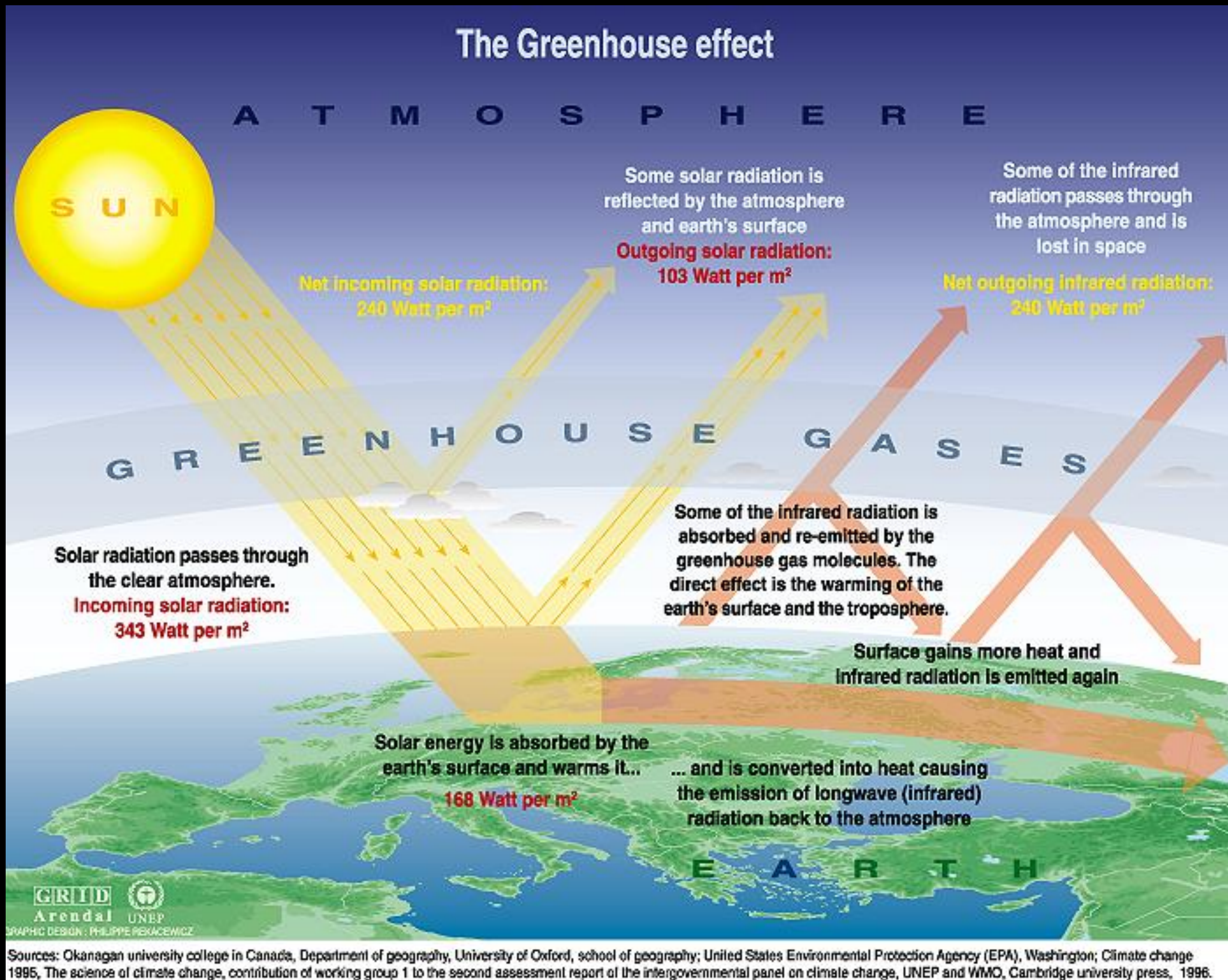
$$T_e = [S_0(1-a_p) / 4\sigma]^{1/4}$$

T_e = emission temp

S_0 = solar "constant"

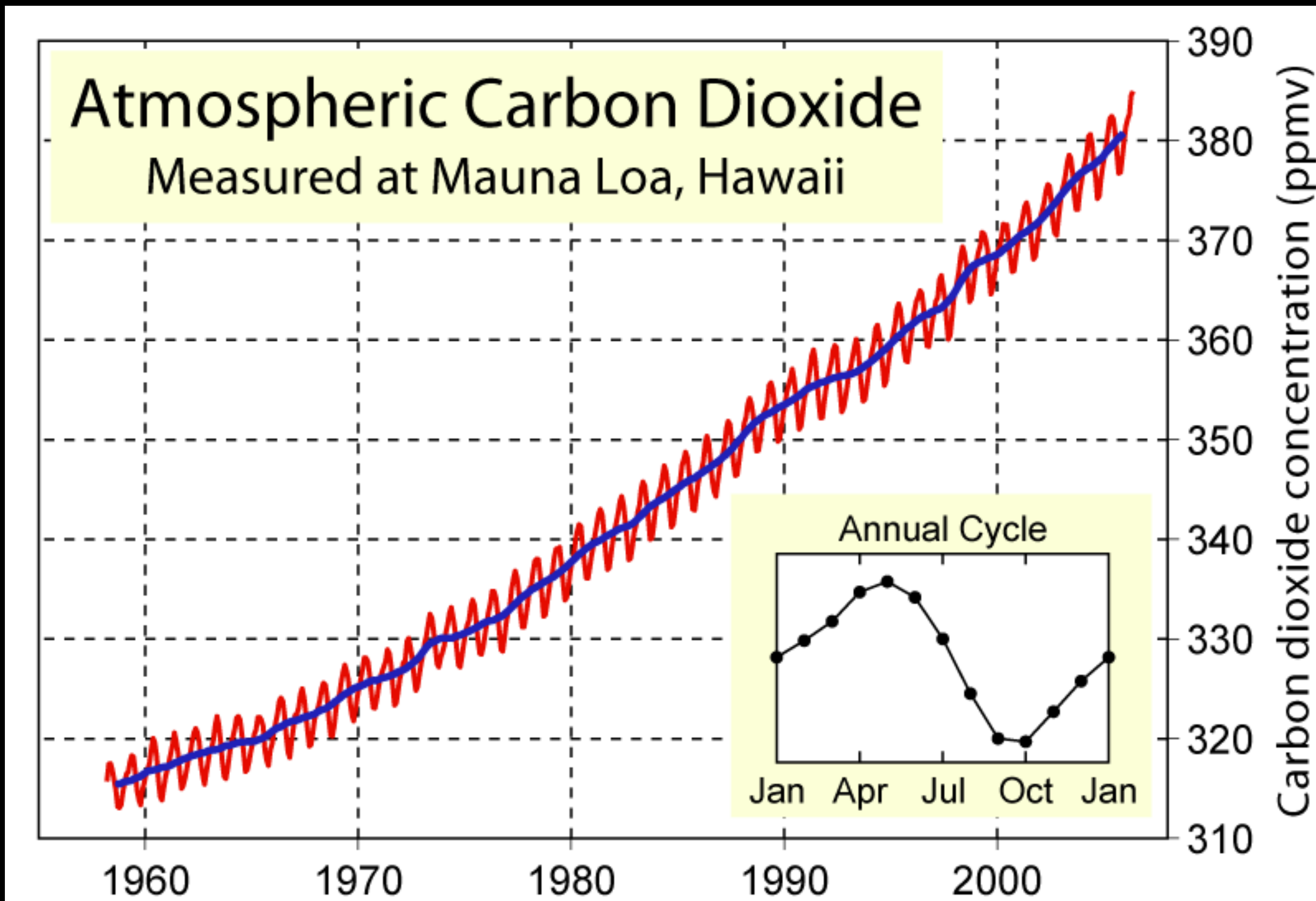
a_p = planetary albedo

σ = Stefan-Boltzman constant


The Greenhouse effect
ATMOSPHERE
SUN
Some solar radiation is reflected by the atmosphere and earth's surface
Outgoing solar radiation: 103 Watt per m²
Some of the infrared radiation passes through the atmosphere and is lost in space
Net incoming solar radiation: 240 Watt per m²
Net outgoing infrared radiation: 240 Watt per m²
GREENHOUSE GASES
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth's surface and the troposphere.
Solar radiation passes through the clear atmosphere.
Incoming solar radiation: 343 Watt per m²
Surface gains more heat and infrared radiation is emitted again
Solar energy is absorbed by the earth's surface and warms it...
168 Watt per m²
... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere
EARTH
GRID Arendal
UNEP
GRAPHIC DESIGN : PHILIPPE REKACEWICZ
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

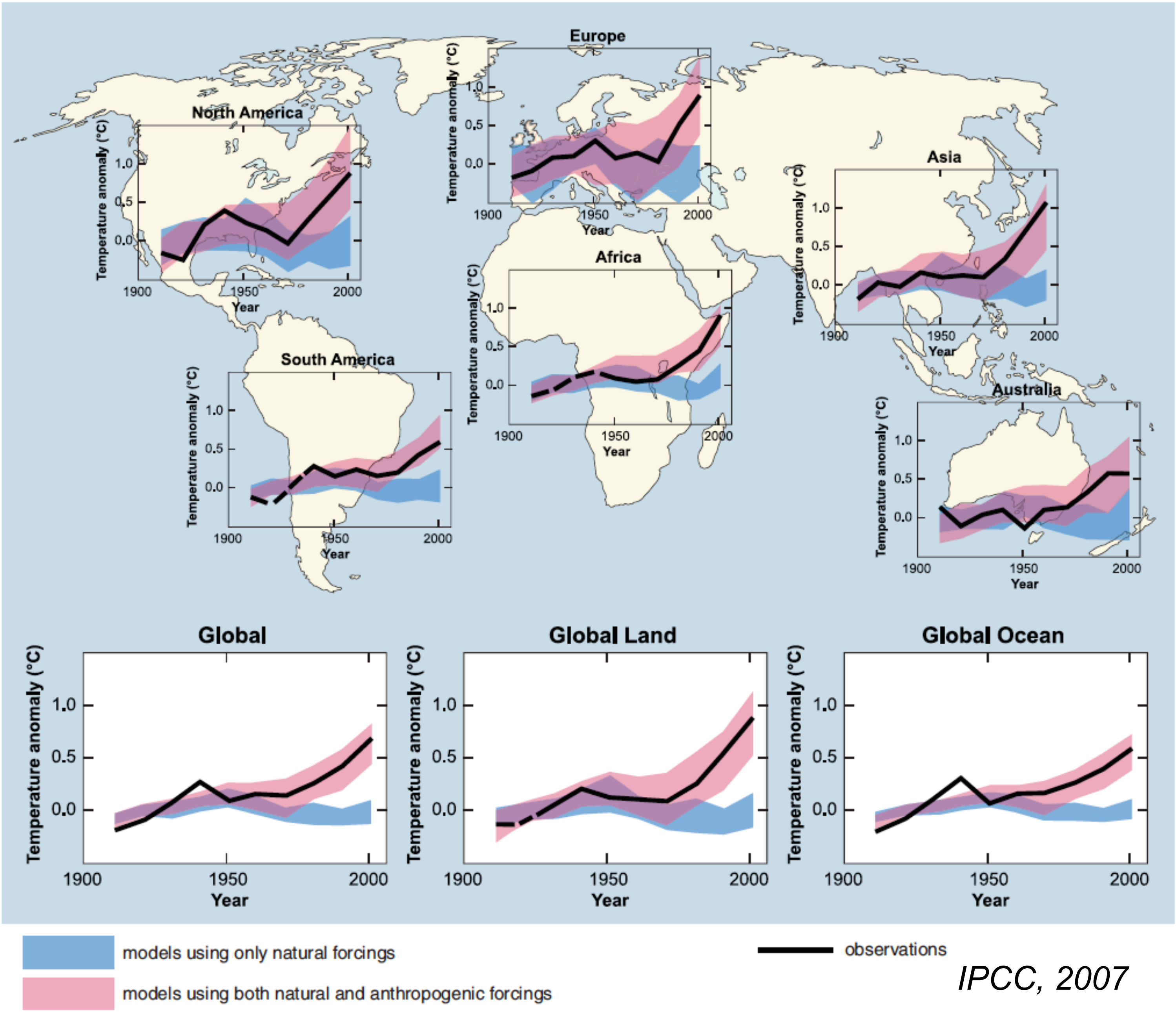
IPCC

Keeling Curve



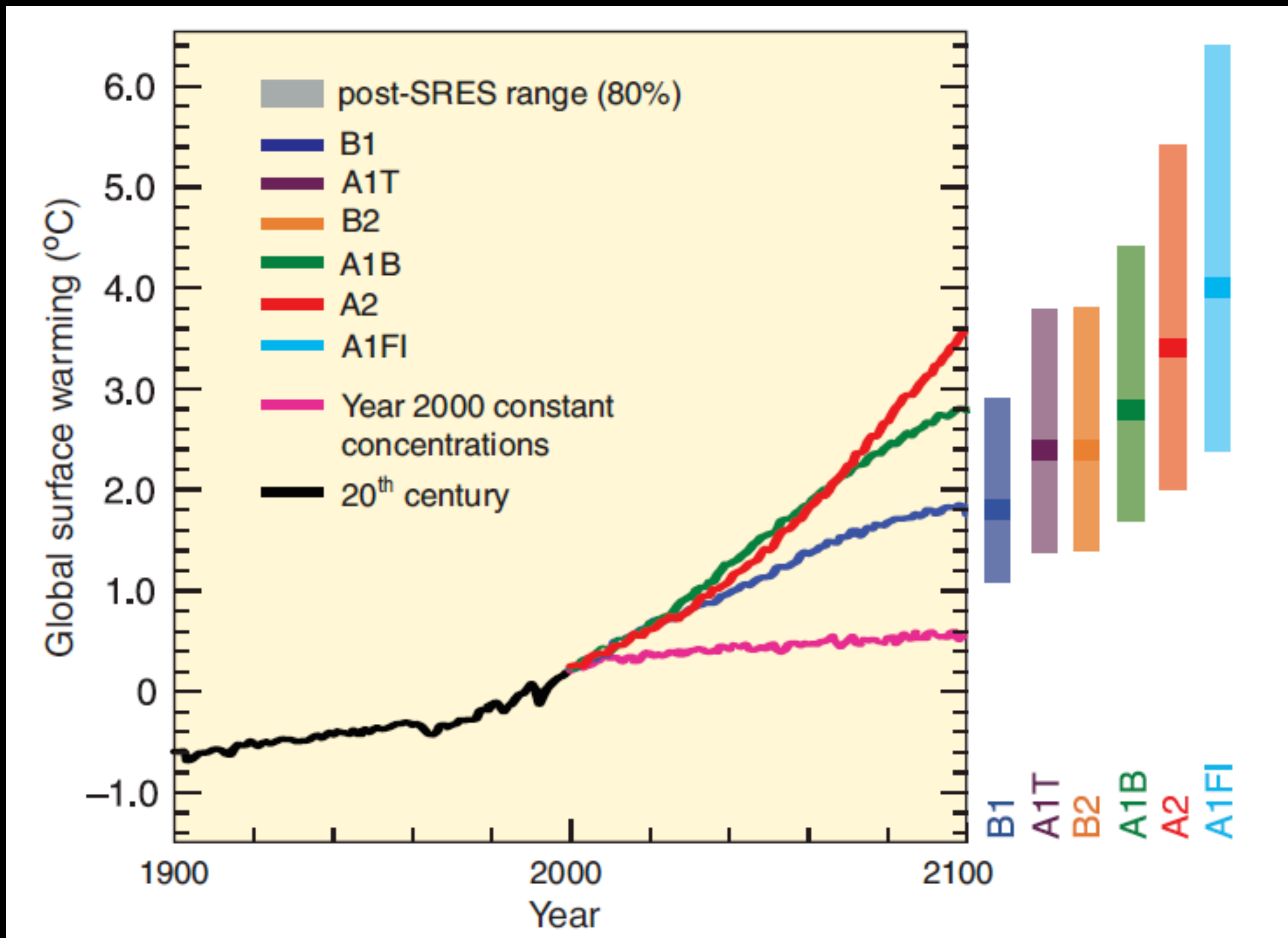
Global Warming Art

Global and continental temperature change



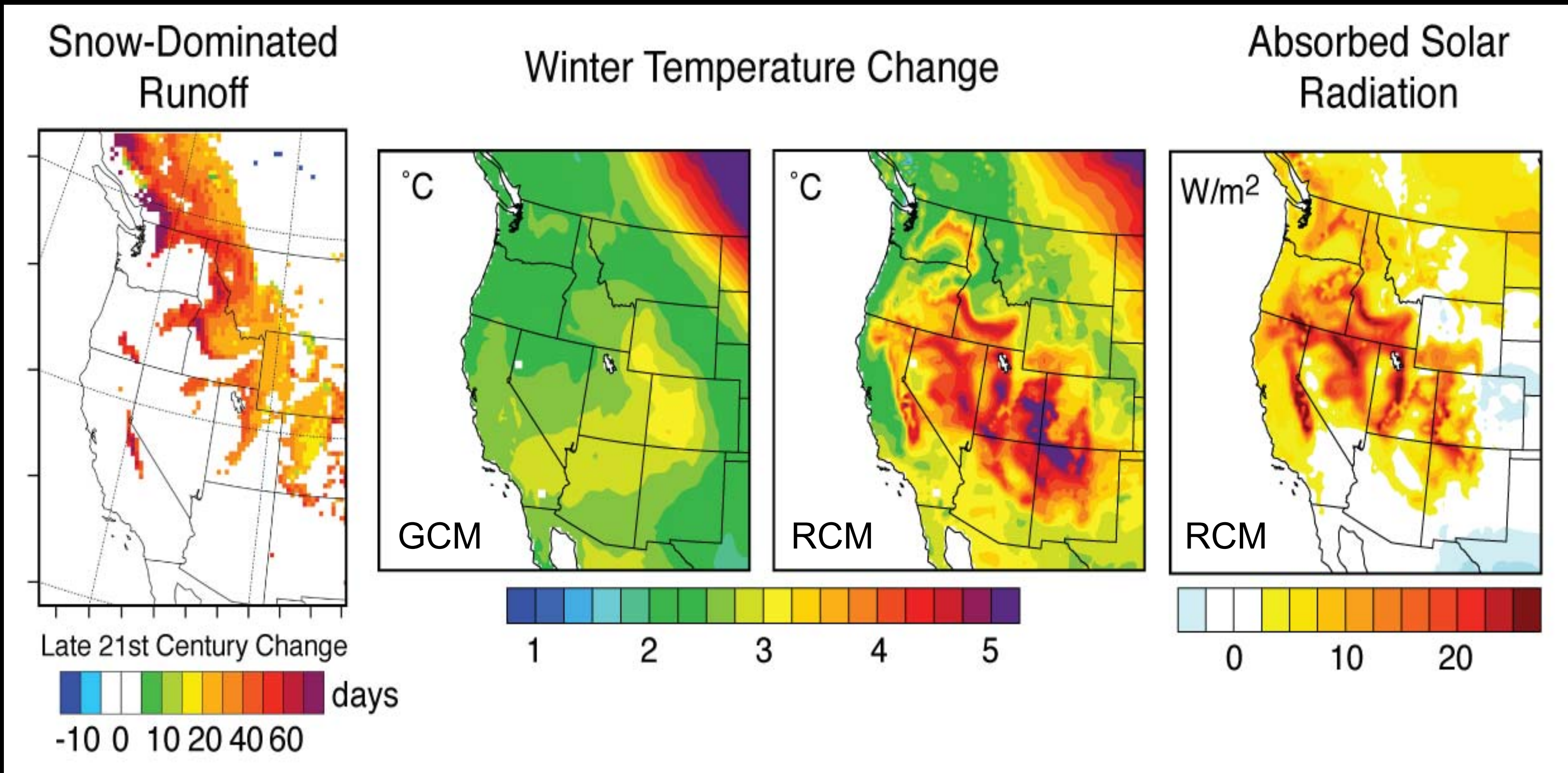
IPCC, 2007

What might happen if climate changes?



IPCC, 2007

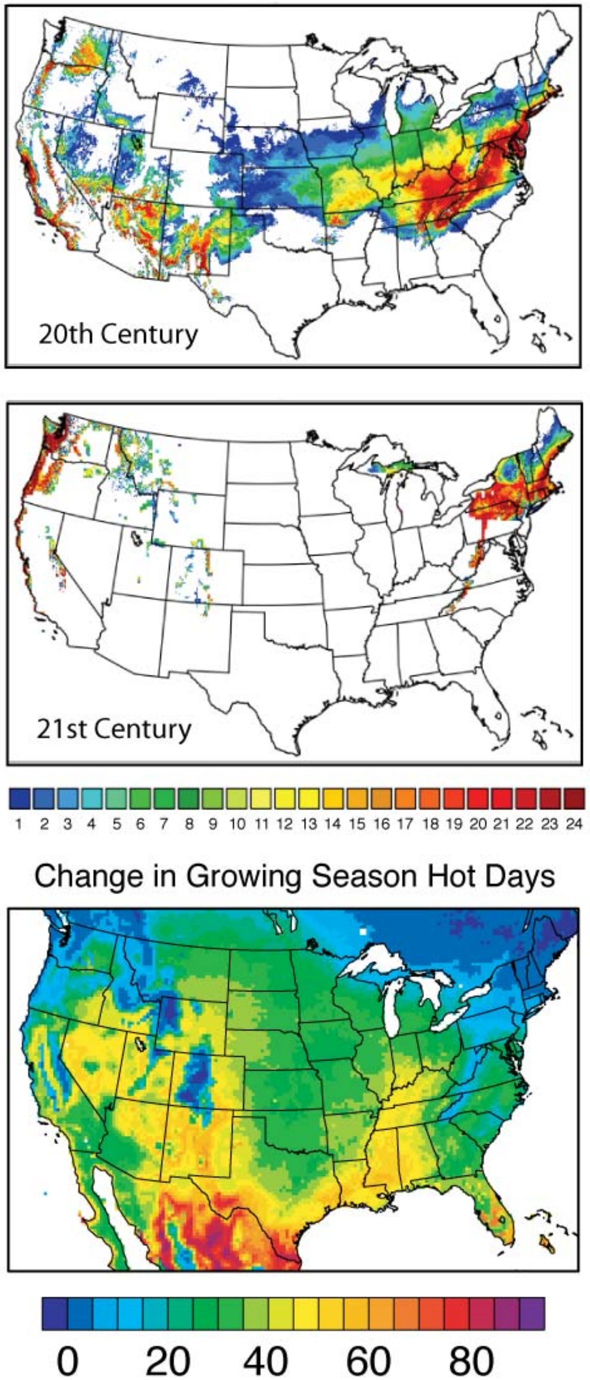
A2: 2071-2099 minus 1961-1989



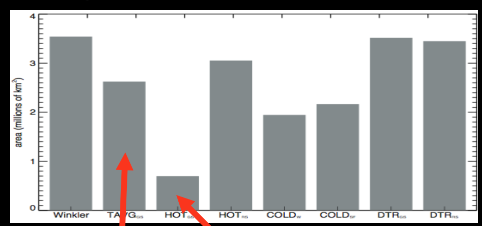
=> The climate change in the high-resolution projection is twice as large as in the GCM because of improved representation of the physical climate system.

Rauscher et al., GRL, 2008

Premium Wine Production



Suitable Area



Mean Seasonal Temperature

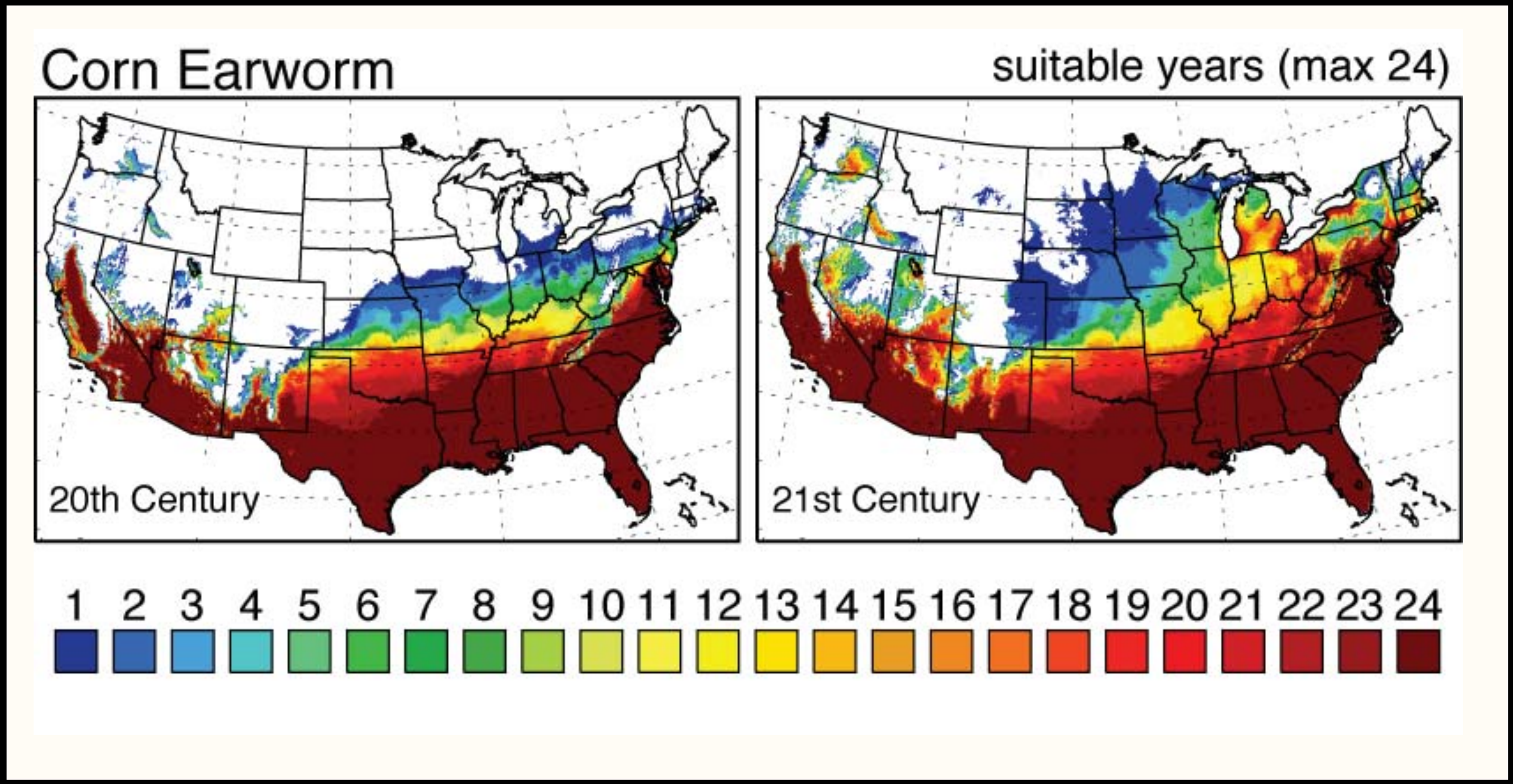
Extreme Daily Heat

- Response of wine production driven by response of severe heat

- Response of severe heat varies spatially

White et al., PNAS, 2006

Agricultural Pest Prevalence

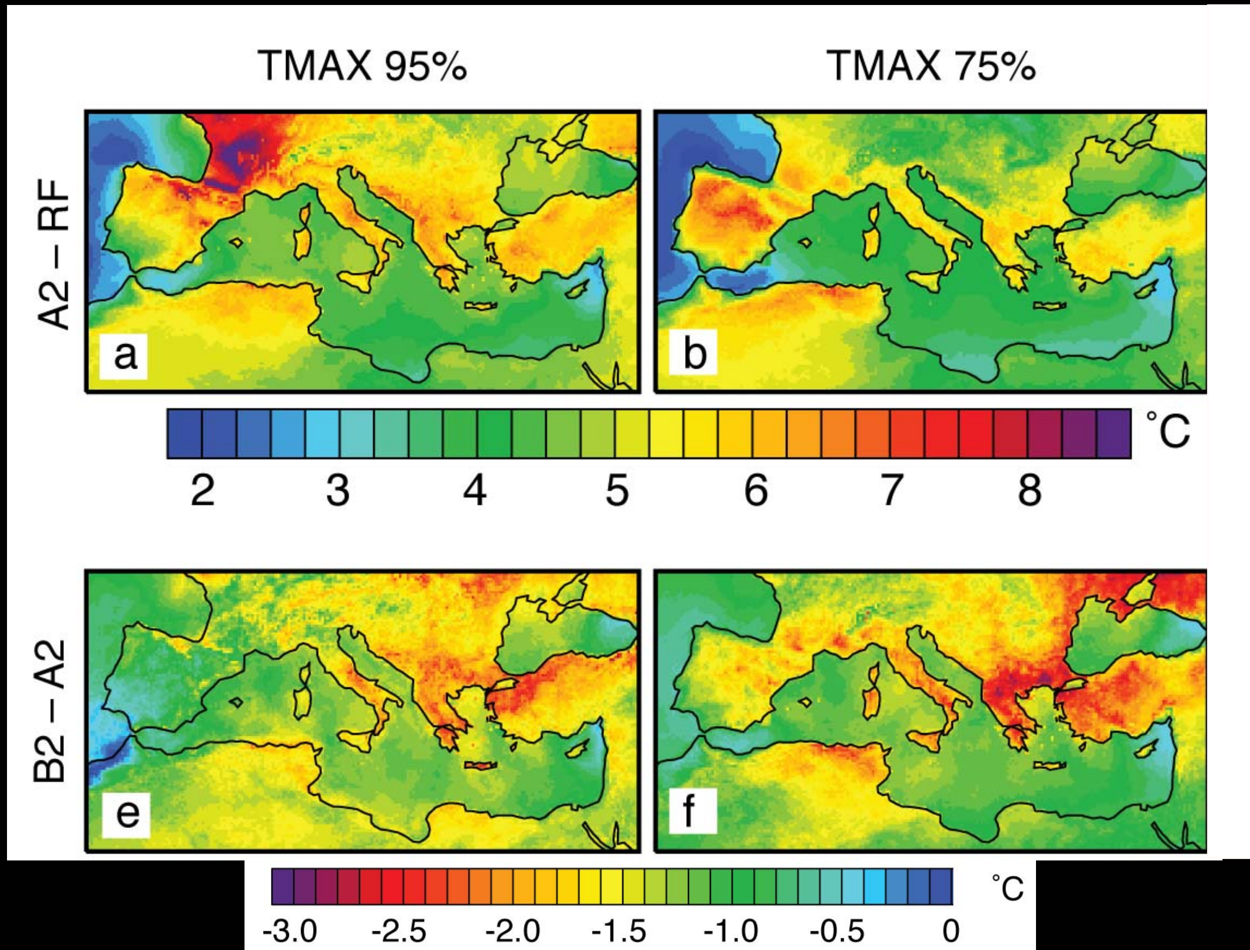


- Migratory, cosmopolitan, with strong pesticide resistance

- Expansion of range due to relaxation of severe cold limitation

Diffenbaugh et al., ERL, 2008

"Deceleration Effect"

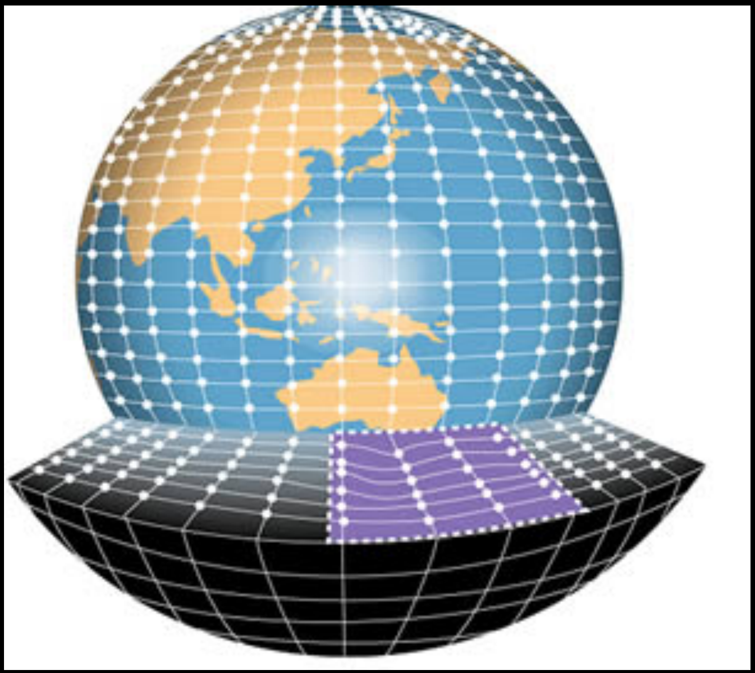


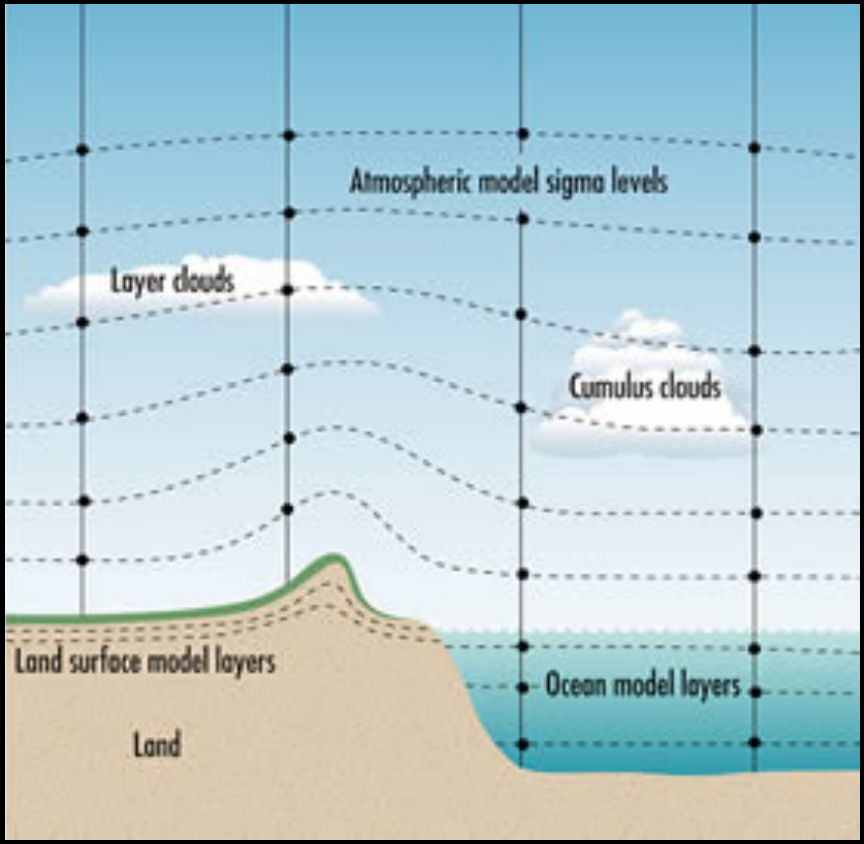
- Reduced mitigation "savings" due to surface moisture feedback
- Value of GHG mitigation is non-uniform, particularly for critical thresholds

Diffenbaugh et al., GRL, 2007

How Quickly Can Severe Climate Change Emerge?

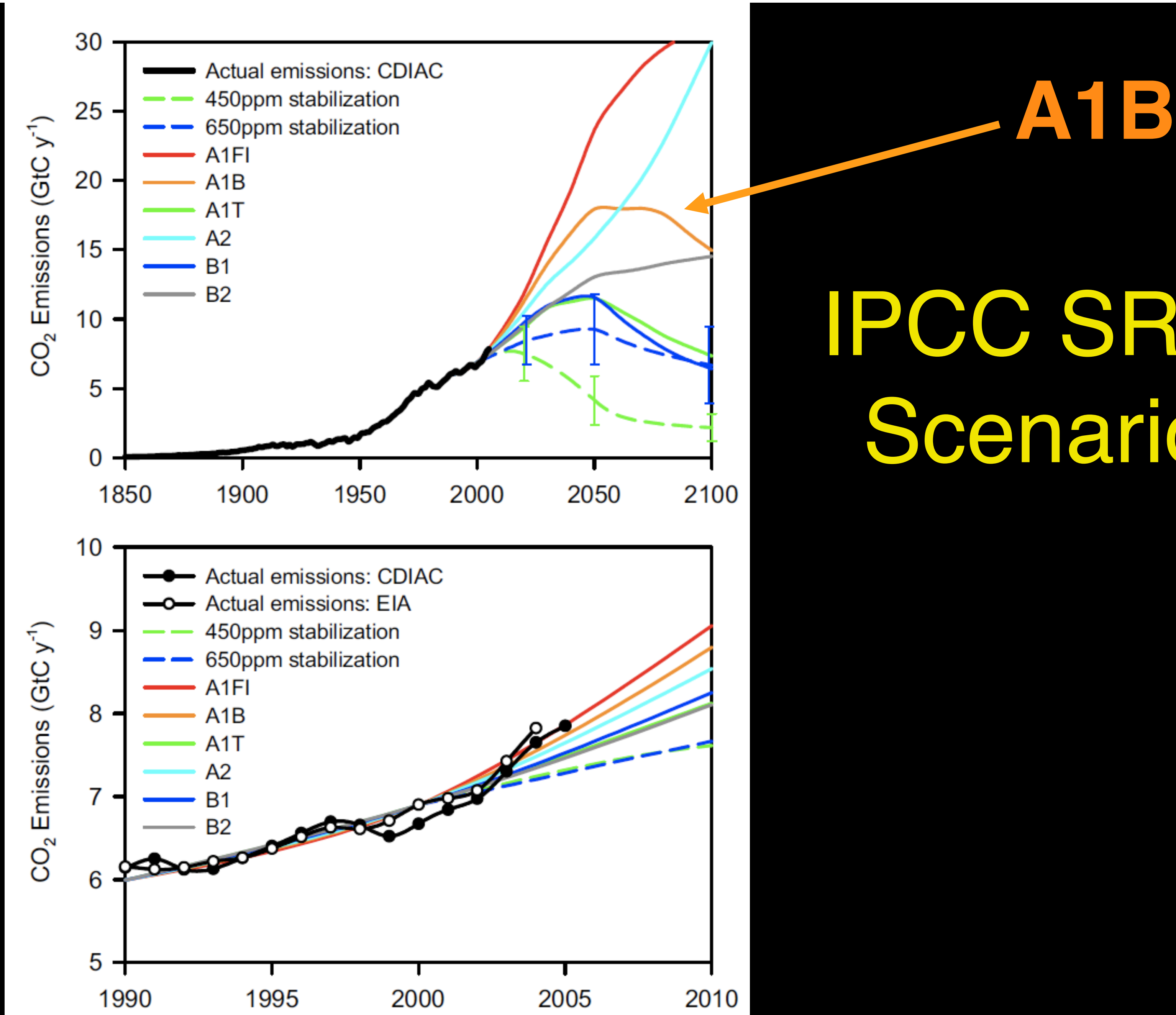
General Circulation Model ("GCM")





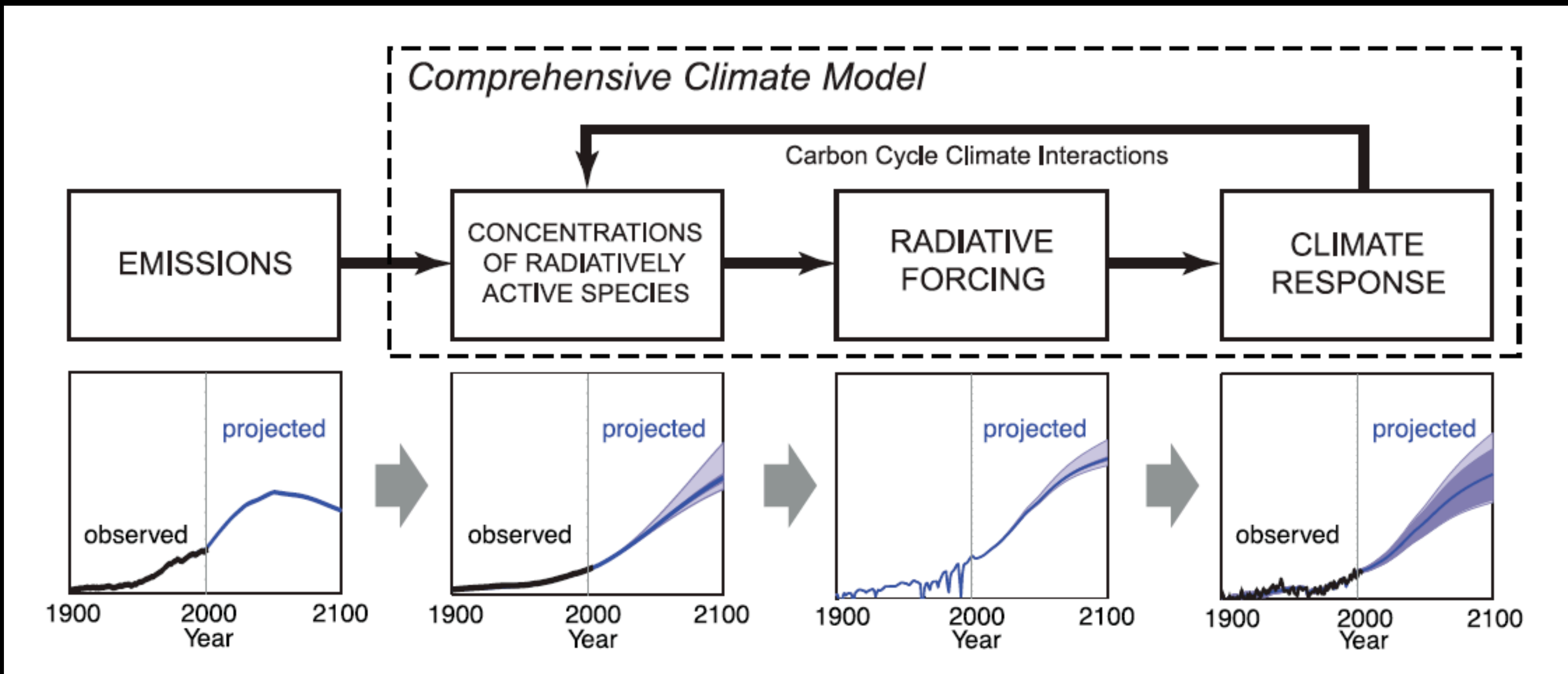
Laws of Physics!!!

Australia Government BOM



IPCC SRES Scenarios

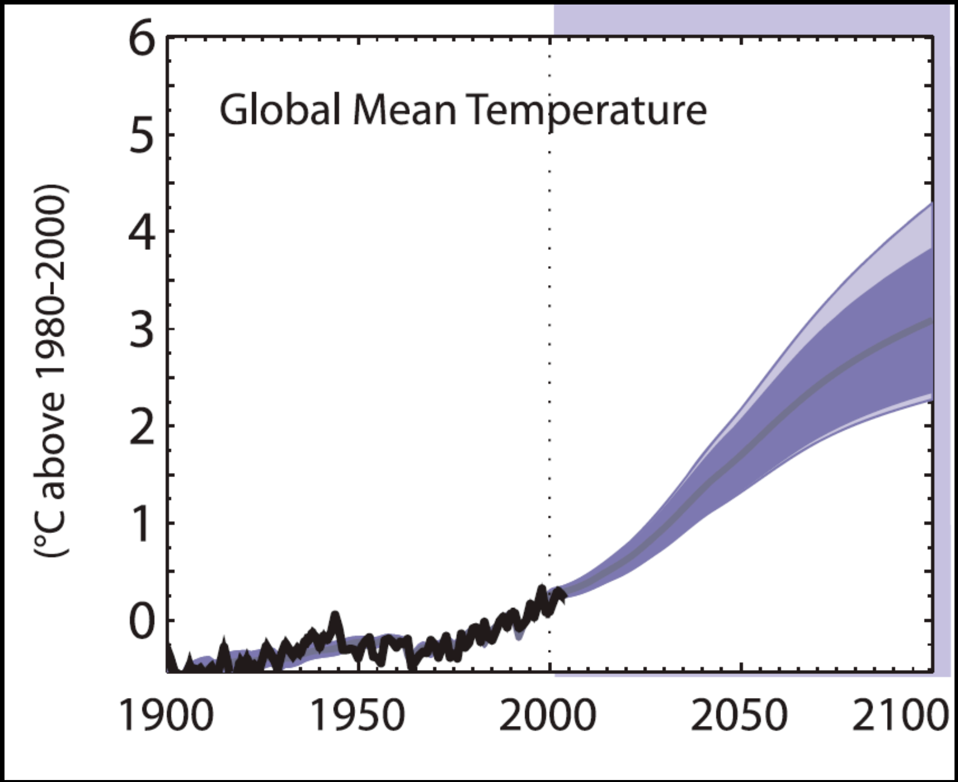
Raupach et al., 2007


Comprehensive Climate Model
Carbon Cycle Climate Interactions
EMISSIONS
CONCENTRATIONS OF RADIATIVELY ACTIVE SPECIES
RADIATIVE FORCING
CLIMATE RESPONSE
projected
observed
1900
2000
2100
Year
projected
observed
1900
2000
2100
Year
projected
1900
2000
2100
Year
projected
observed
1900
2000
2100
Year

IPCC, 2007

21st Century Global Warming

Many Models (A1B)



IPCC, 2007

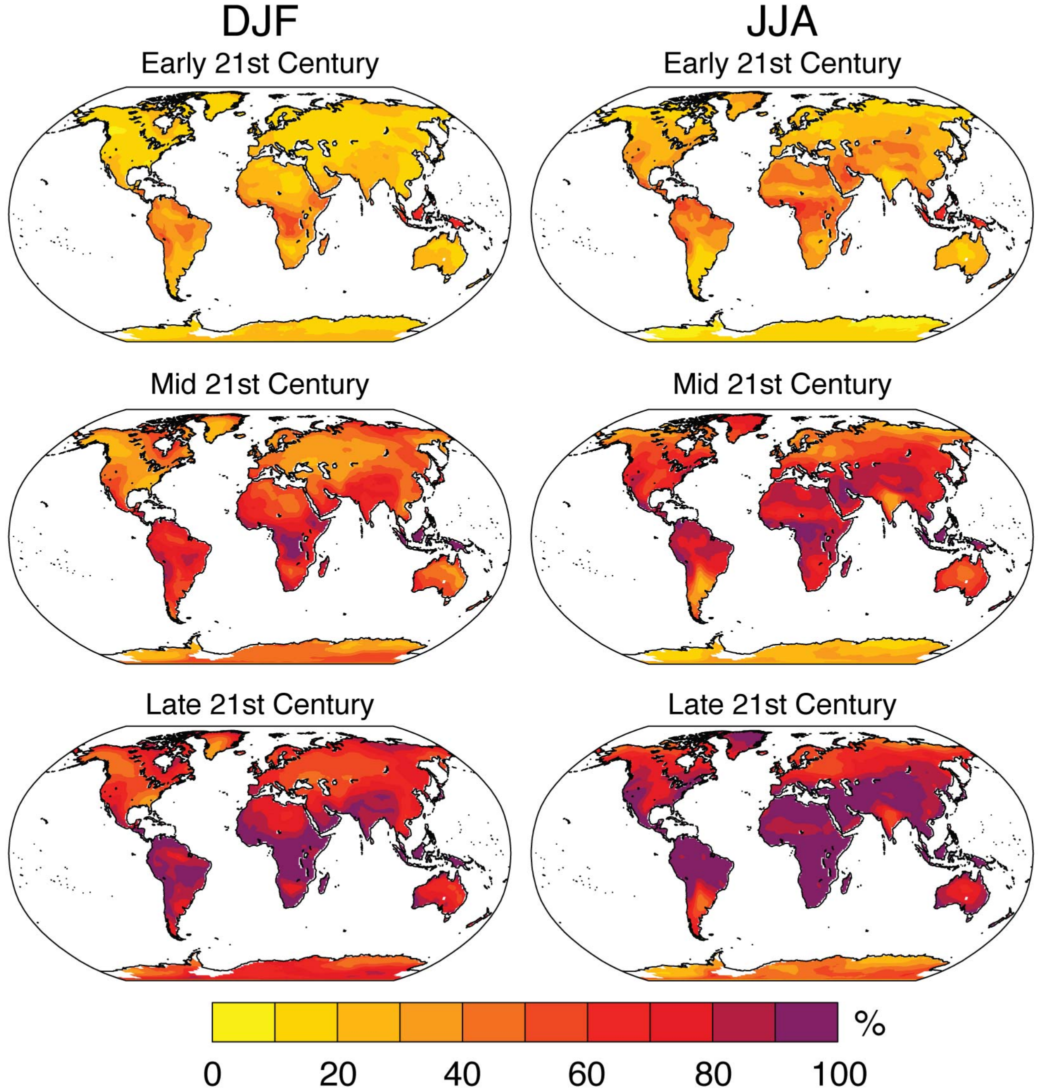
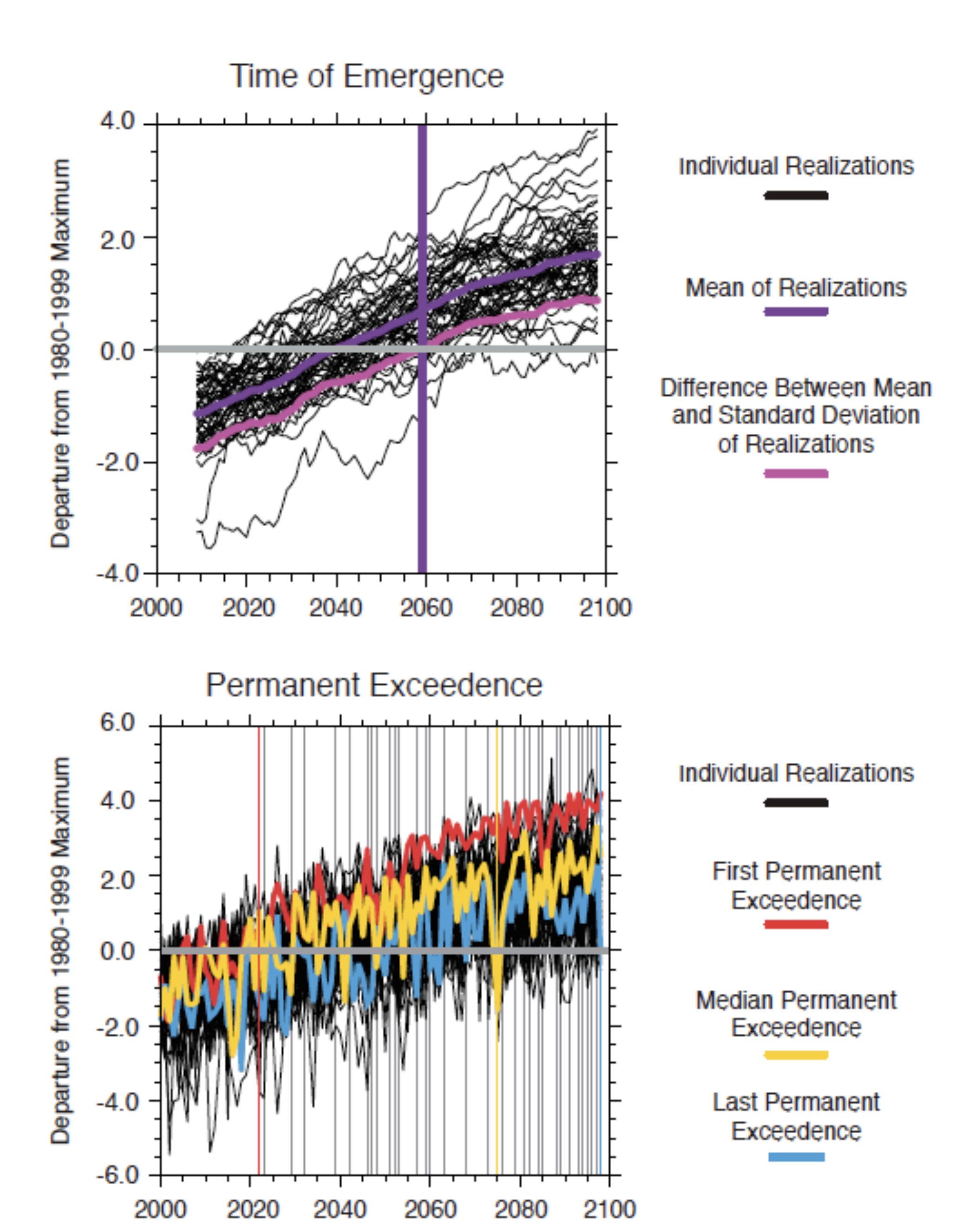


Figure 1. The percentage of seasons in the CMIP3 A1B ensemble for which the surface air temperature exceeds the the warmest season of the 1980-1999 period. The early 20th century period is 2010-2039, the mid 20th century period is 2040-2069, and the late 20th century period is 2070-2098.


Time of Emergence
Departure from 1980-1999 Maximum
4.0
2.0
0.0
-2.0
-4.0
2000
2020
2040
2060
2080
2100
Individual Realizations
Mean of Realizations
Difference Between Mean and Standard Deviation of Realizations
Permanent Exceedence
Departure from 1980-1999 Maximum
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
2000
2020
2040
2060
2080
2100
Individual Realizations
First Permanent Exceedence
Median Permanent Exceedence
Last Permanent Exceedence

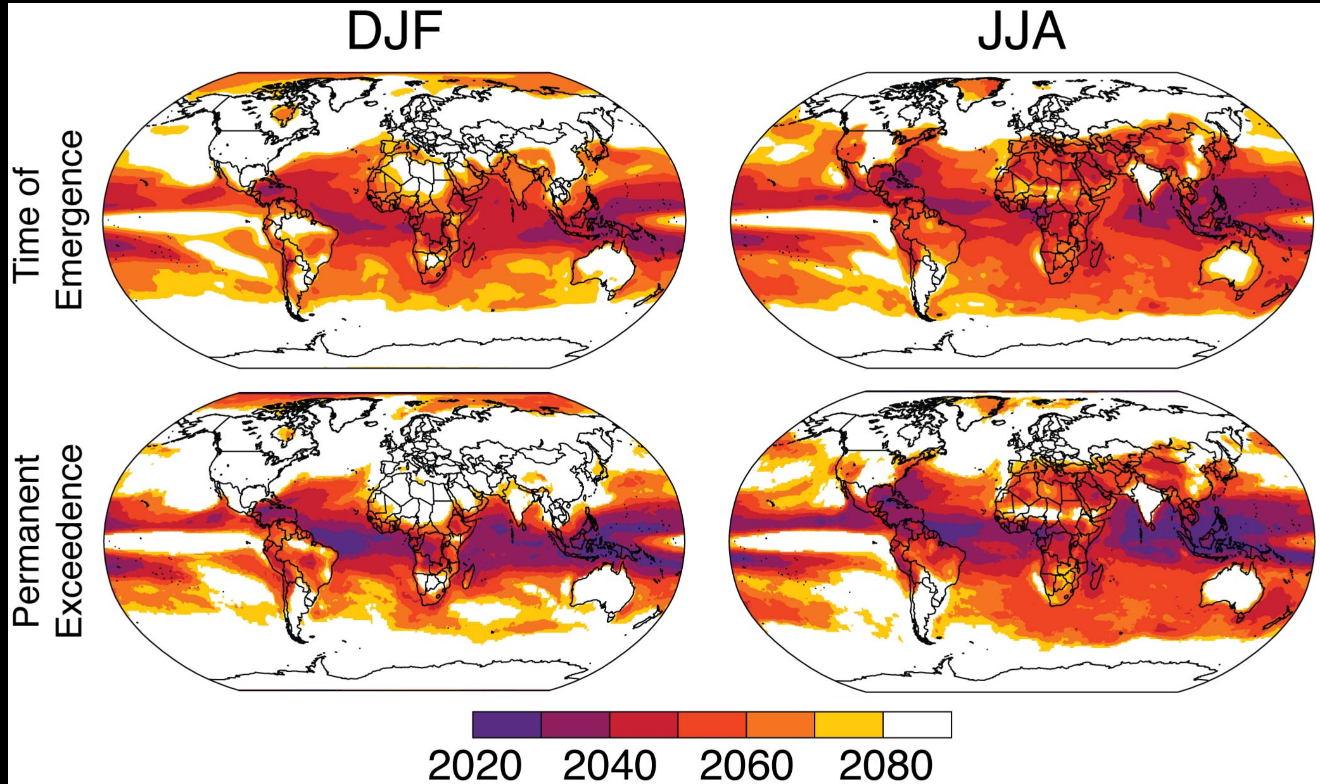


Figure 2. Decade of emergence of extreme surface air temperature. The top row shows the time of emergence (TOE) of the ensemble signal, calculated as the decade in which the ensemble mean seasonal temperature difference from the 1980-1999 maximum becomes permanently greater than the spread (one standard deviation) between the individual member differences from the 1980-1999 maximum. The second row shows the decade of the last occurrence of a season that is cooler than the 1980-1999 maximum, calculated as the median of the values across the CMIP3 ensemble. We cannot confirm whether the exceedence is permanent beyond the end of the 21st century, and therefore eliminate dates after 2080. Further details of both metrics are given in the text, and in Fig. S1.

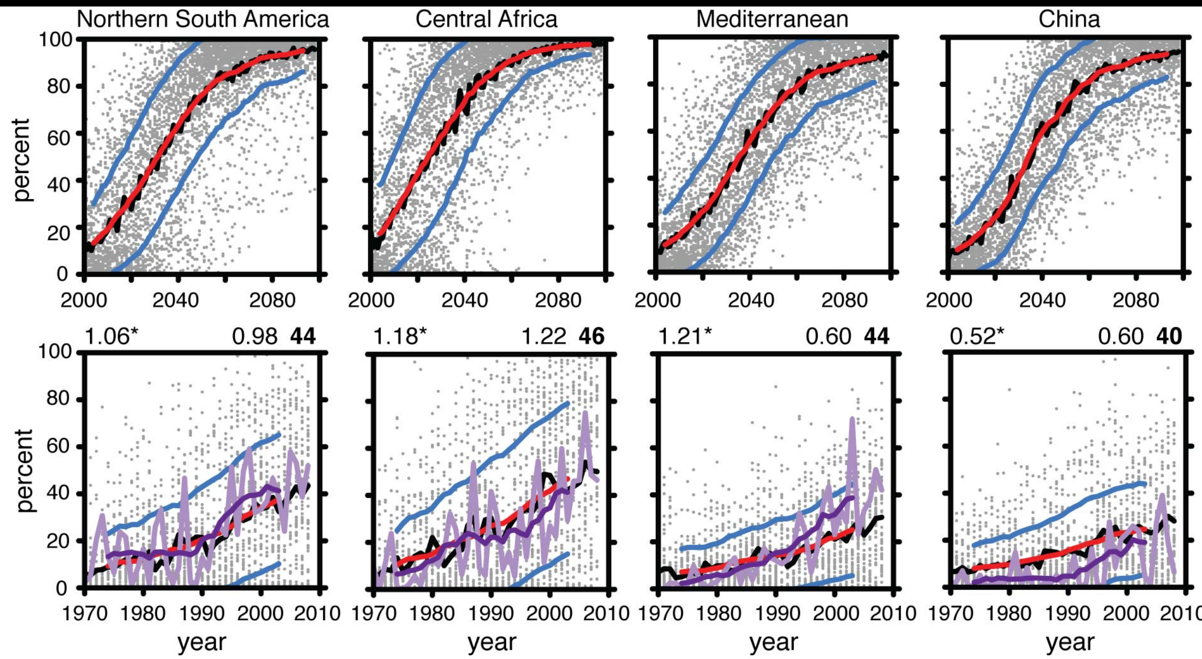


Figure 3. Time series of exceedence of historical temperature extreme. Top row: Time series of the fraction of land grid points with JJA surface air temperatures above the respective 1980-1999 maximum. Bottom row: Time series of the fraction of land grid points with JJA surface air temperatures above the respective 1952-1969 maximum. The grey points denote this fraction for each CMIP3 model realization. The black curves show the mean across all realizations. The red curves show the 10-year running mean of the mean across all realizations. The blue curves show the 10-year running mean of a one-standard-deviation range across the mean of all realizations. The light purple shows the observational timeseries. The dark purple curves show the 10-year running mean of the observational timeseries. The regions cover land areas in Northern South America (25S-3N, 82-33W), Central Africa (1S-13N, 18W-51E), the Mediterranean (28-50N, 12W-38E), and China (21-43N, 97-123E). The trend in the observational timeseries (% per year) is shown in the upper left of the bottom panels, with those trends that are statistically significant identified with a *. The mean of the trends in the CMIP3 realizations is shown in the upper right of the bottom panels, with the number of realizations that exhibit a statistically significant trend shown in bold.

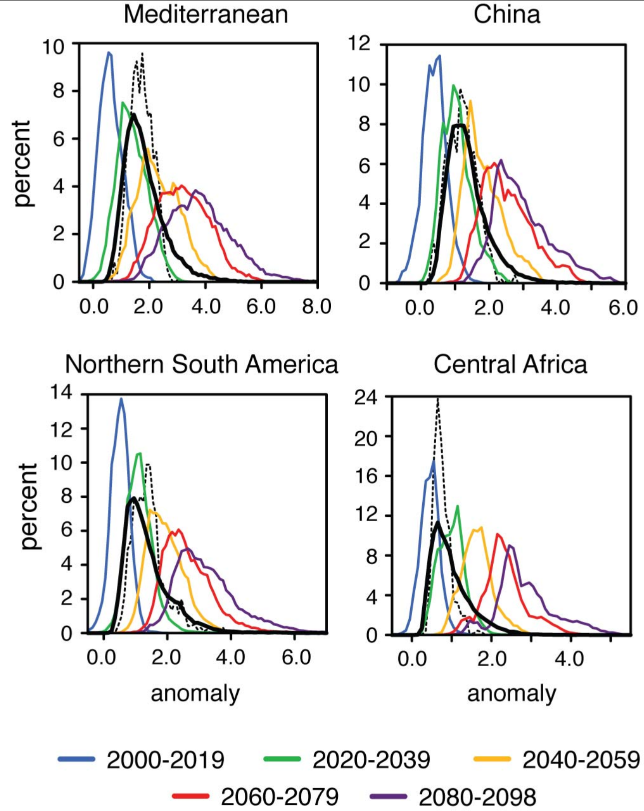
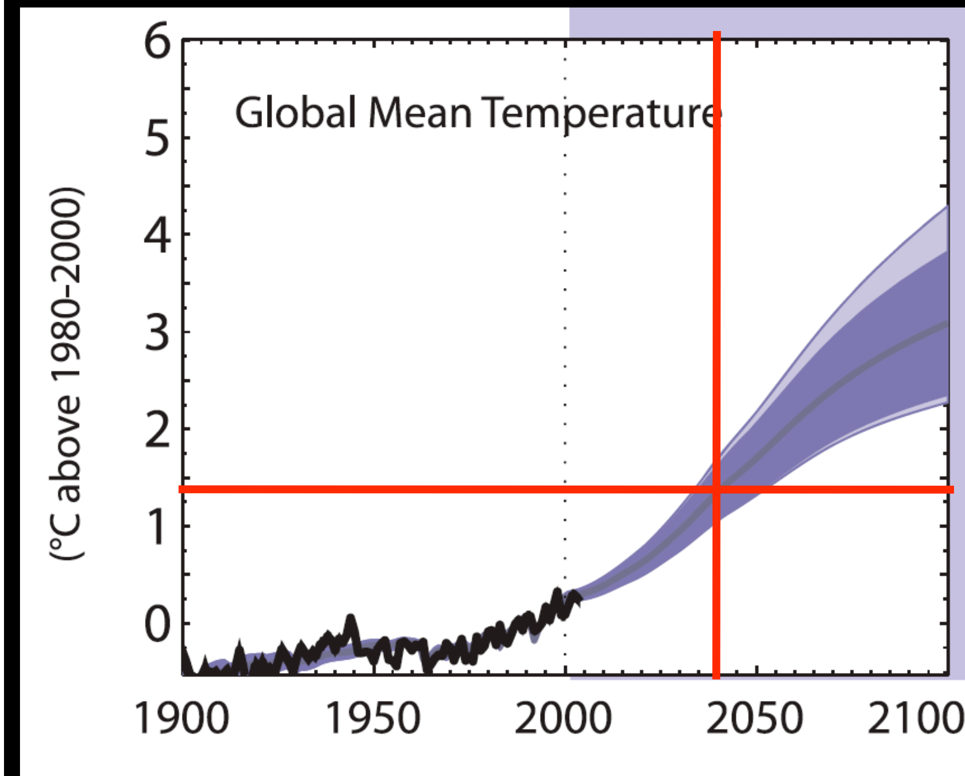


Figure 4. Probability density function (PDF) of JJA surface air temperature anomalies over land for four regions (Mediterranean, China, Northern South America and Central Africa). Each colored PDF represents anomalies for the CMIP3 ensemble for a 2-decade period of the 21st century (relative to the 1980-1999 period). The black lines show the PDF of the differences between the mean and maximum for the 1980-1999 period, with solid black lines showing the CMIP3 values and dashed lines showing the observed values. Regions are as in Figure 3.

Near-Term Global Warming

Many Models (A1B)



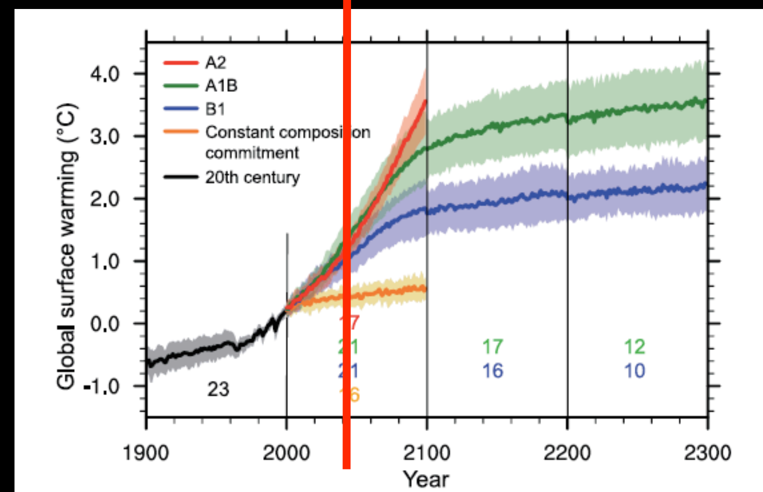


Figure 10.4. *Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulation. Values beyond 2100 are for the stabilisation scenarios (see Section 10.7). Linear trends from the corresponding control runs have been removed from these time series. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means. Discontinuities between different periods have no physical meaning and are caused by the fact that the number of models that have run a given scenario is different for each period and scenario, as indicated by the coloured numbers given for each period and scenario at the bottom of the panel. For the same reason, uncertainty across scenarios should not be interpreted from this figure (see Section 10.5.4.6 for uncertainty estimates).*

IPCC, 2007

1 ˚C additional global warming

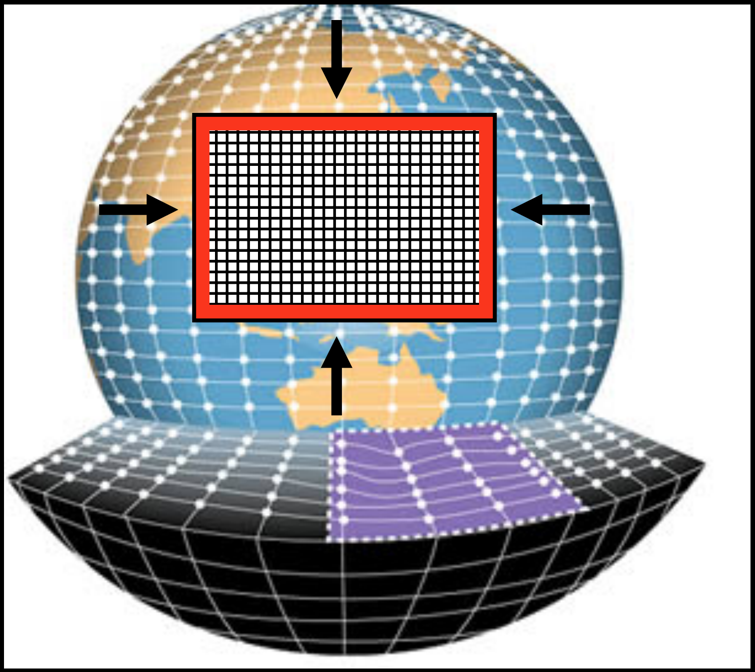
↓

> 50% chance of every warm season being hotter than late-20th century maximum over much of the globe

Question 1: Why is 2˚C the “Target”?

What processes cause intensification in different regions?

Nested High-Resolution Climate Model

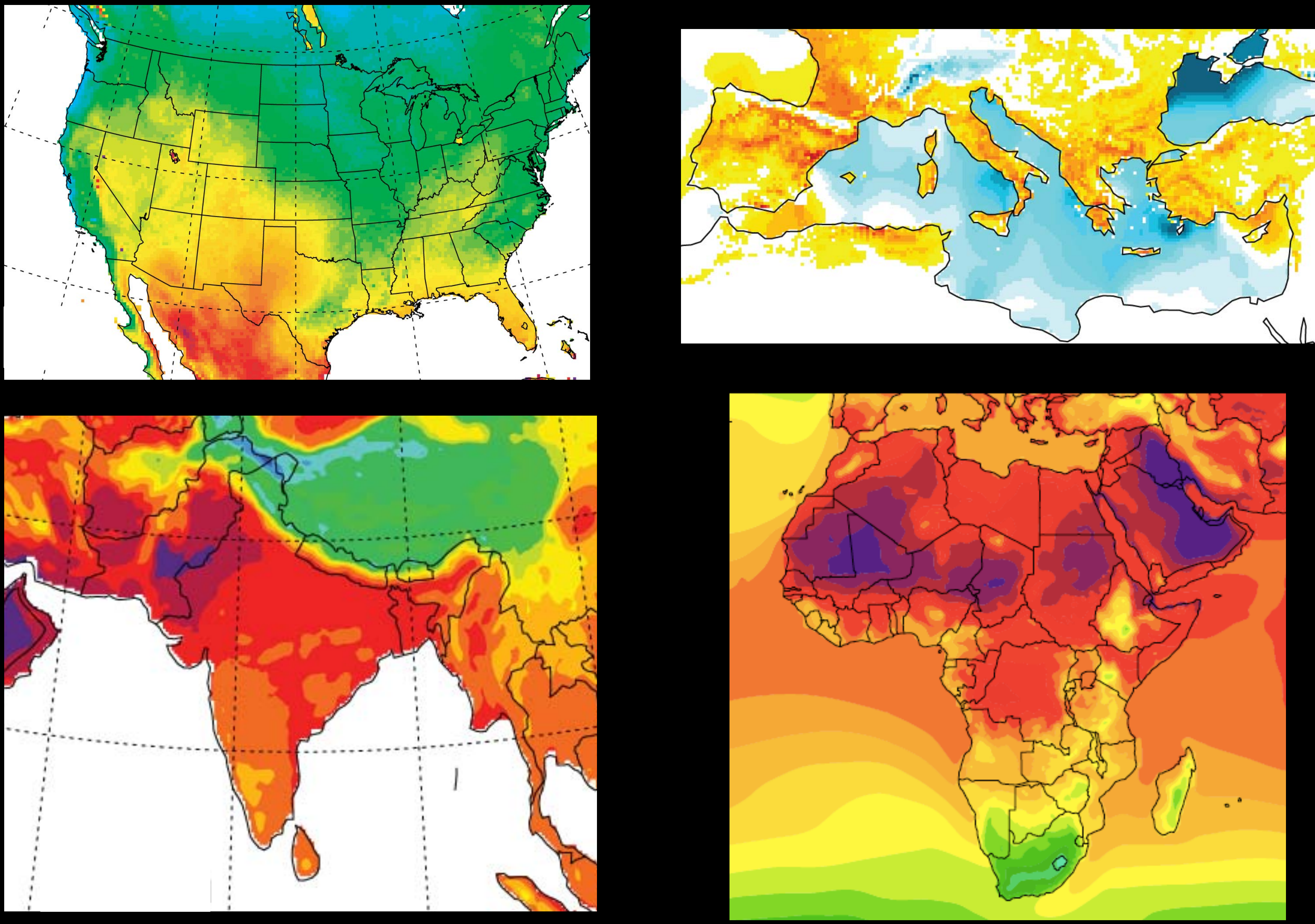


Global ("GCM"):
~125 km horizontal resolution

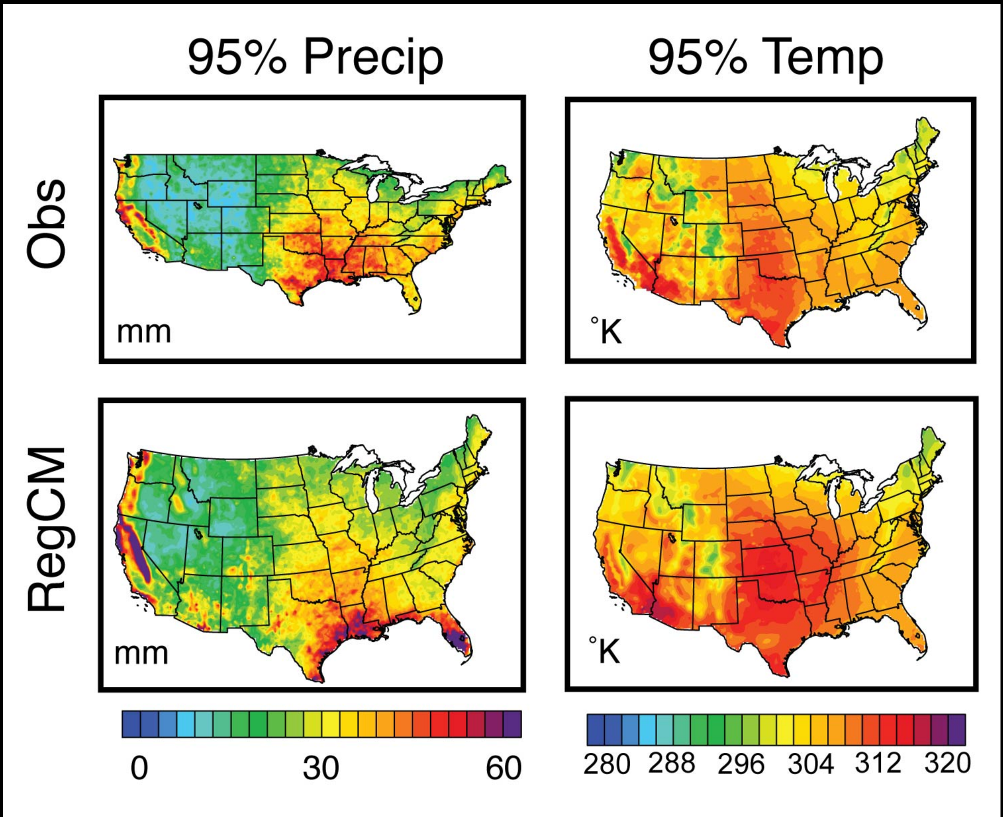
Nested ("RCM"):
~25 km horizontal resolution

Large-scale variables passed to nested model at lateral boundaries every 6 model hours

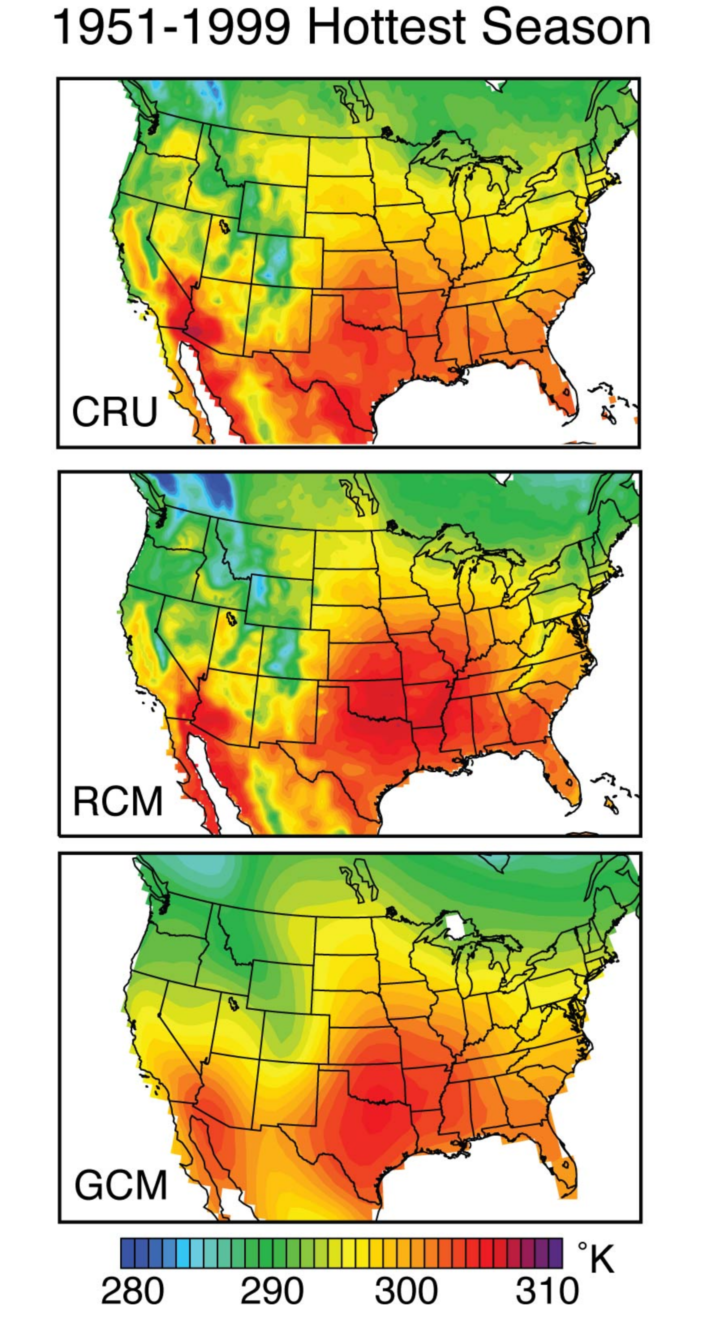
Multiple Regions



Extreme Events

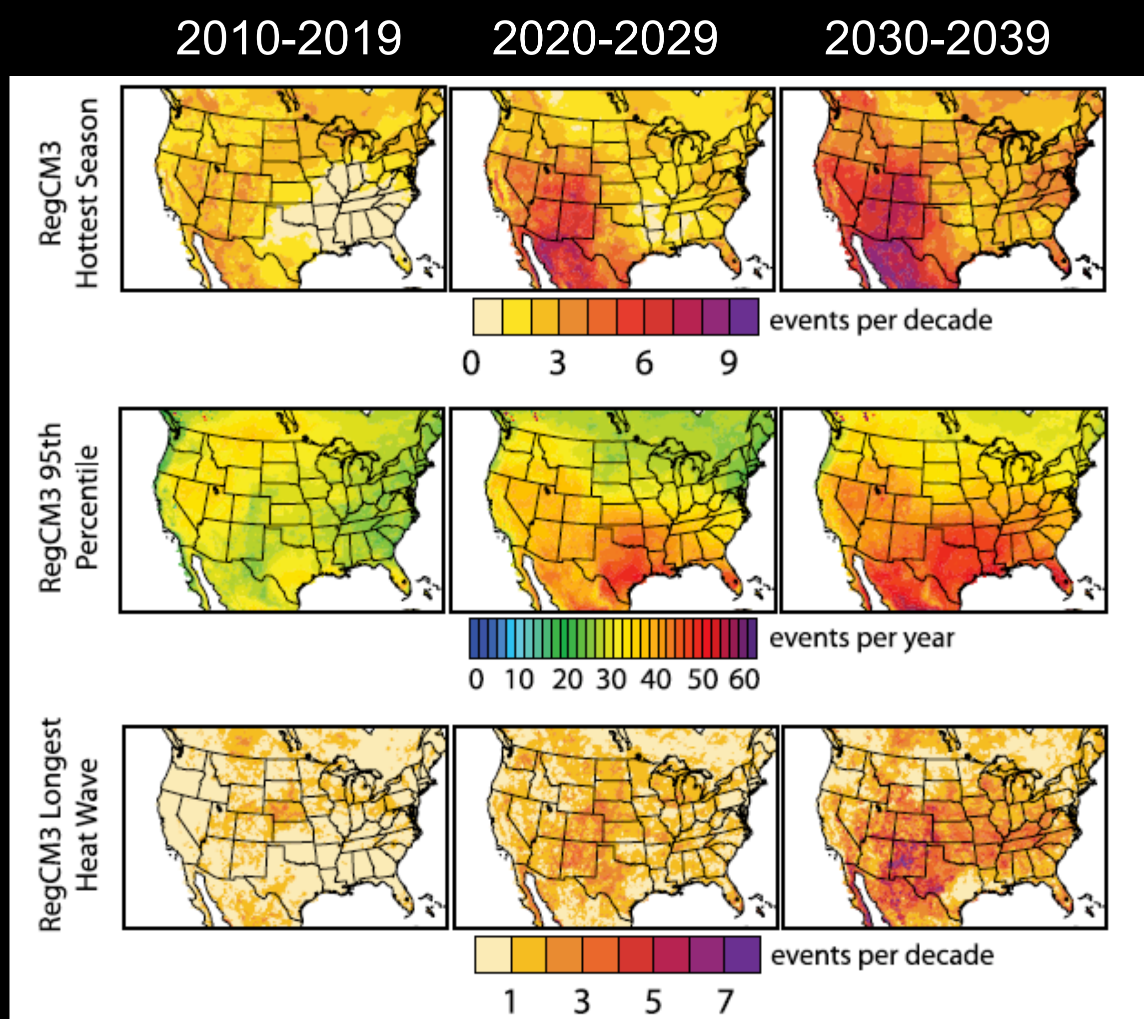


Walker and Diffenbaugh, 2009



Diffenbaugh and Ashfaq, 2010

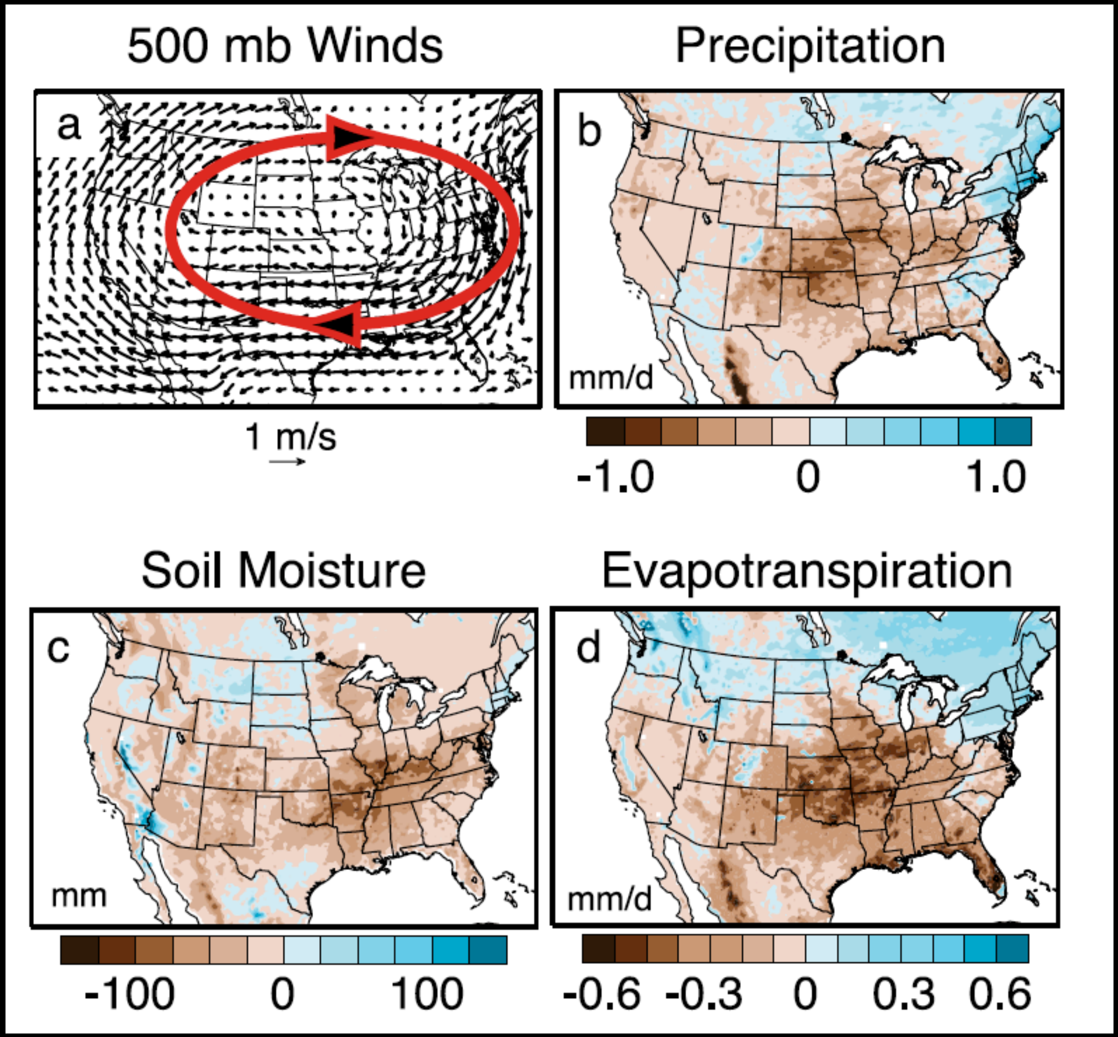
Intensification of Hot Extremes



Diffenbaugh and Ashfaq, 2010

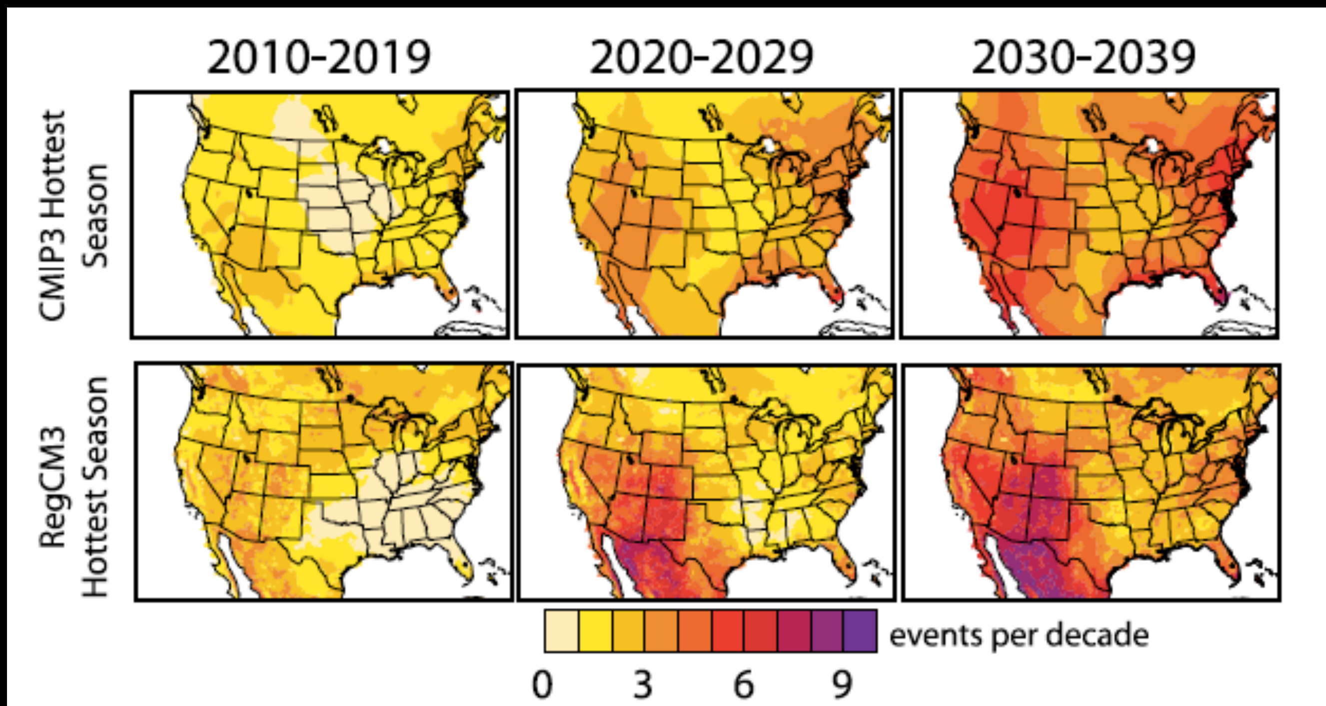
Summer Drying

2030-2039 minus 1980-1999



Diffenbaugh and Ashfaq, 2010

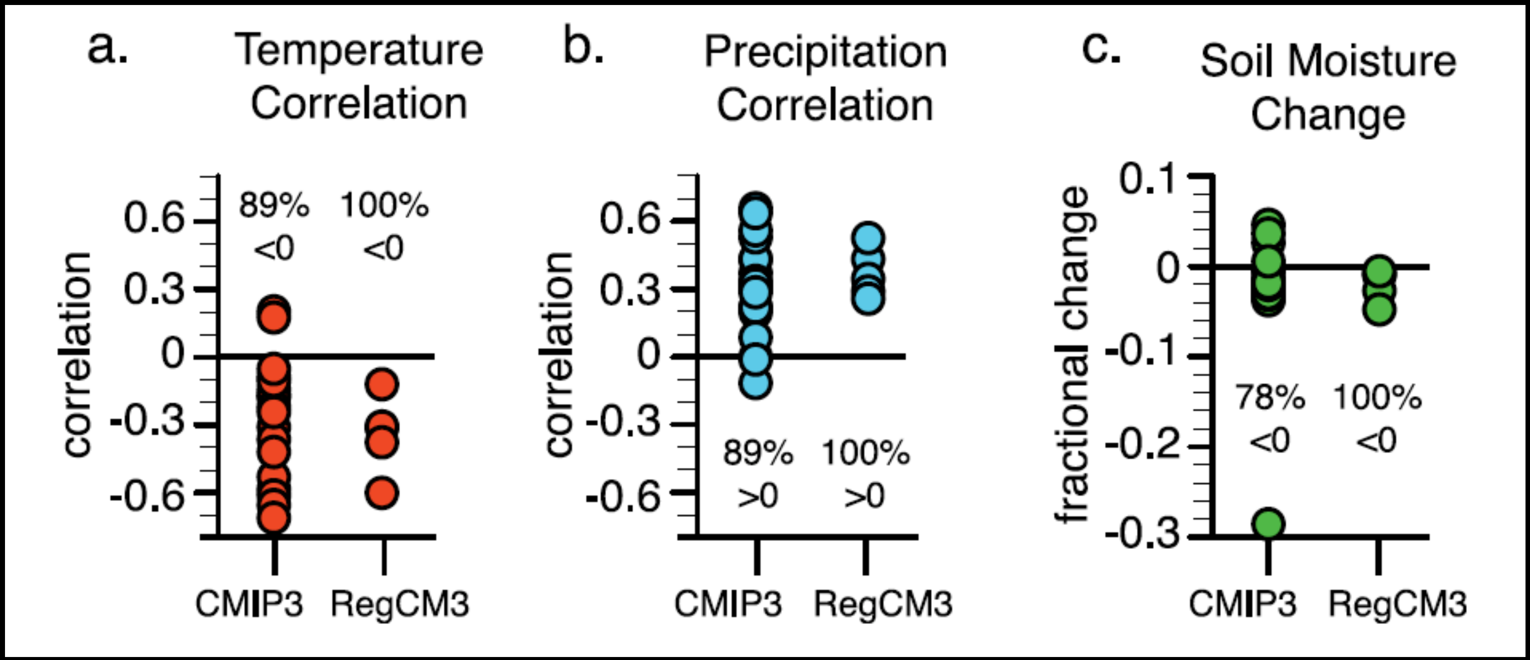
Comparison with “IPCC” GCMs



Diffenbaugh and Ashfaq, 2010

Summer Soil-Moisture/Temperature/ Precipitation Coupling

2030-2039 minus 1980-1999



Diffenbaugh and Ashfaq, 2010

What might be the impacts of such changes?

One Example: Temperature Suitability for Premium Winegrape Cultivation

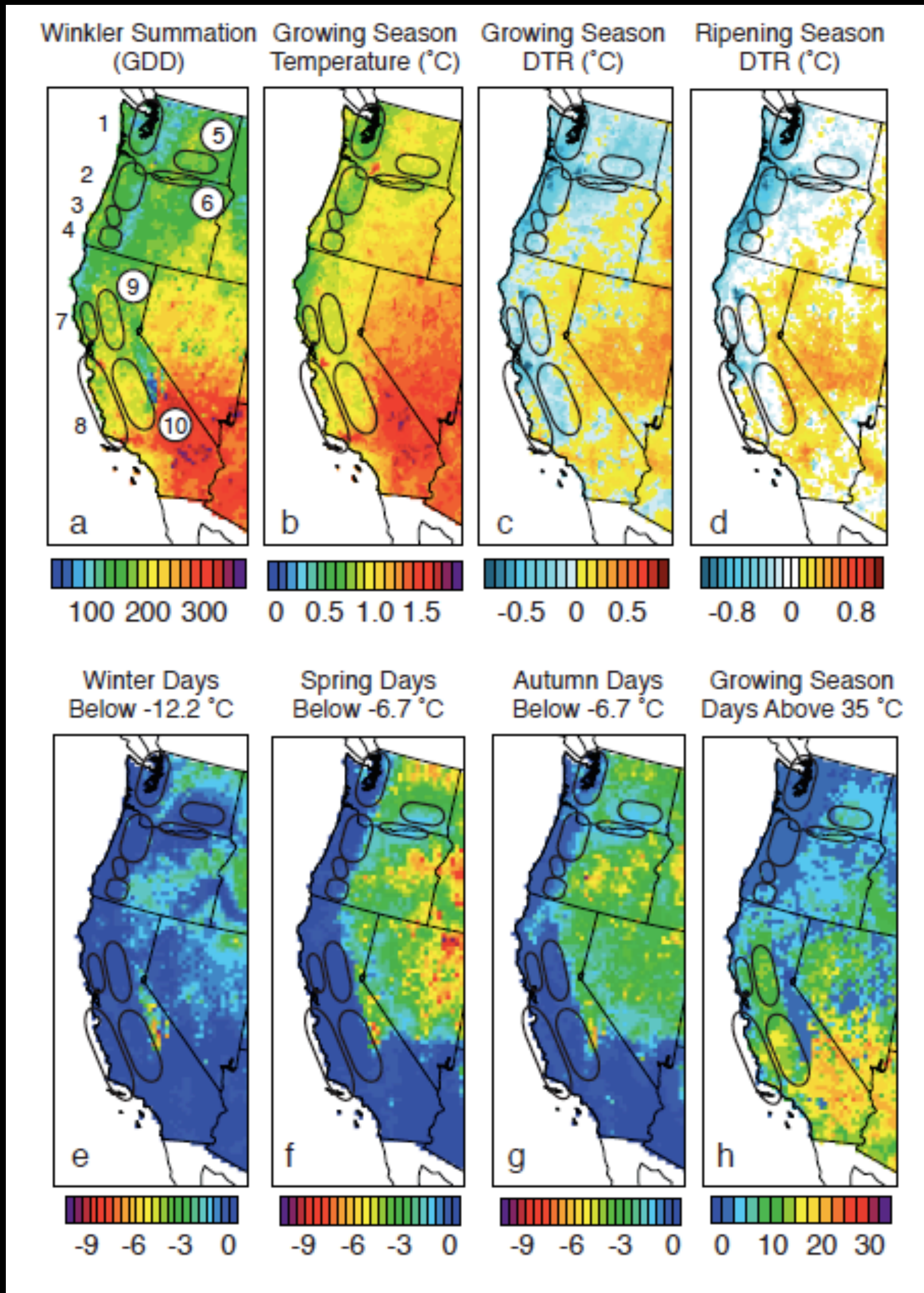
Environ. Res. Lett. **6** (2011) 024024 N S Diffenbaugh *et al*

Table 2. Temperature screening criteria.

Temperature variable	Minimum allowable	Maximum allowable
Growing season[a] growing degree days (GDD)[b]	850 GDD	2700 GDD
Growing season[a] diurnal temperature range (DTR)	—	20 °C
Ripening season[c] diurnal temperature range (DTR)	—	20 °C
Fall[d], winter[e] and spring[f] severe cold days[g]	—	14 days
Growing season[a] severe hot days[h]	—	15–45 days
Growing season[a] mean temperature	13 °C	20–22 °C

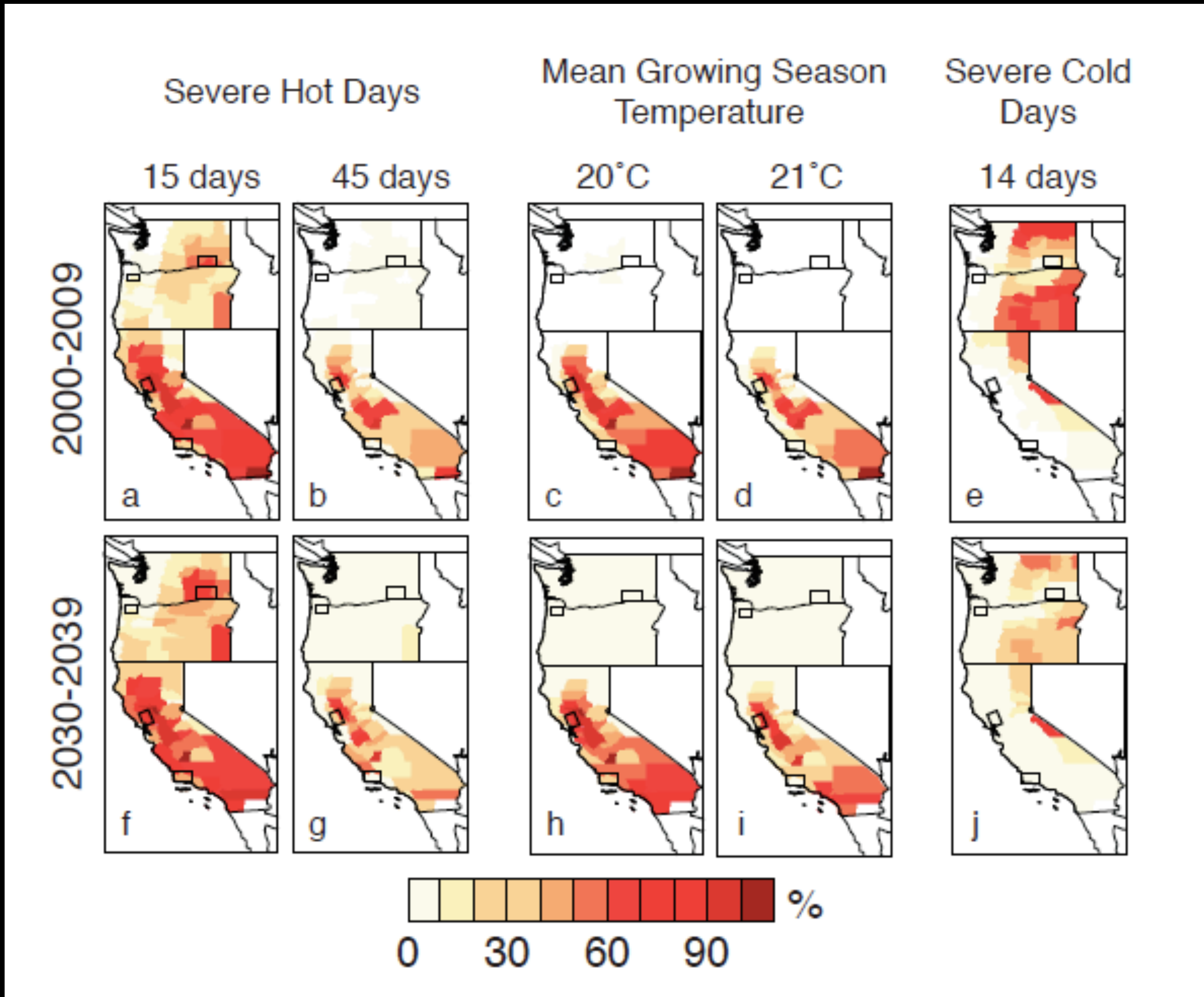
[a] 1 April to 31 October. [b] 15 August to 15 October. [c] Base 10 °C. [d] 1 September to 30 November.
[e] 1 December to 28 February. [f] 1 March to 31 May.
[g] Total of fall days below −6.7 °C, Winter days below −12.2 °C, and Spring days below −6.7 °C.
[h] Days above 35 °C.

- sensitivity to heat and cold; mean and extremes
- variations within and at margins of suitability range

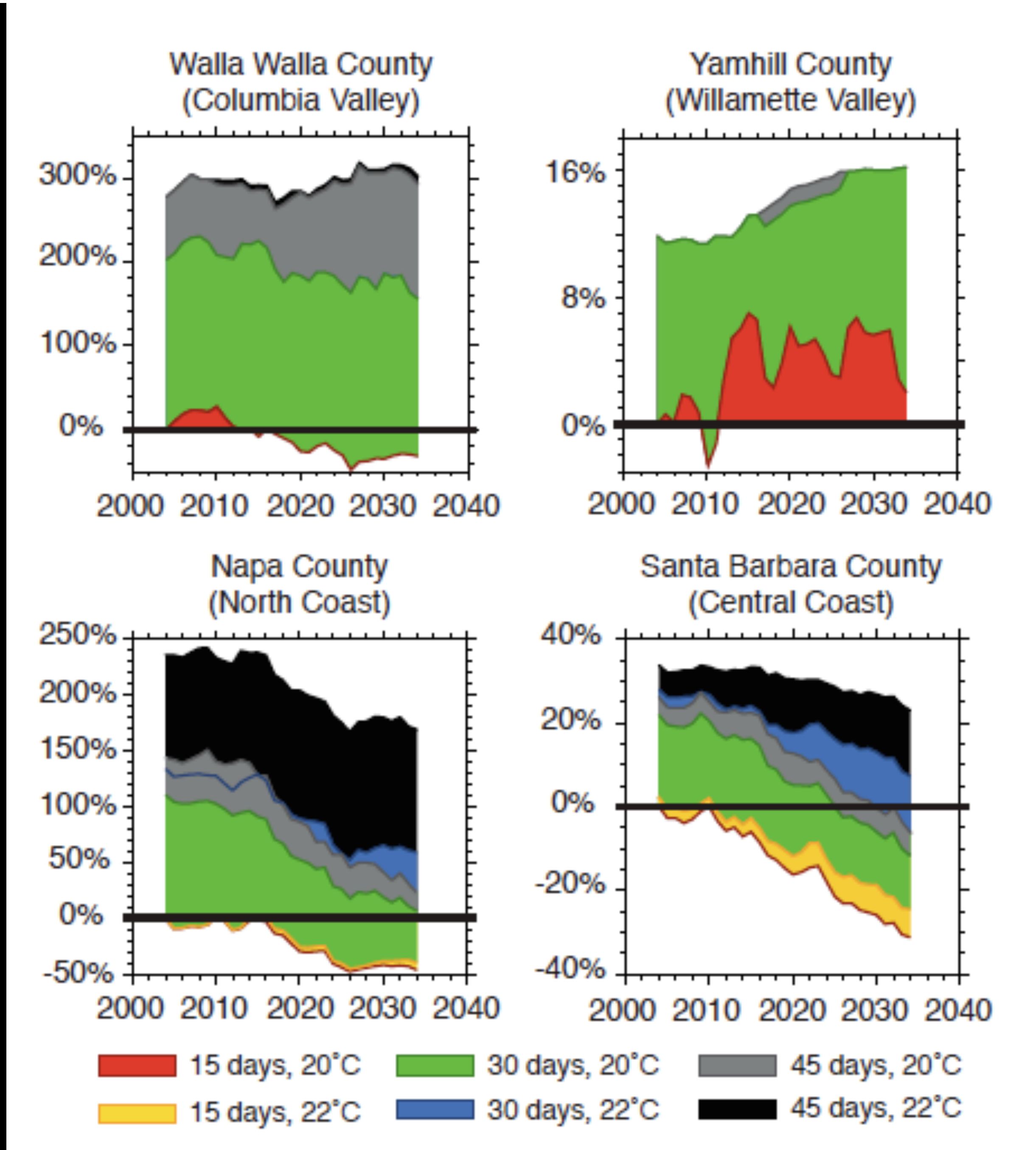


- heterogeneity in changes in temperature criteria, including extremes

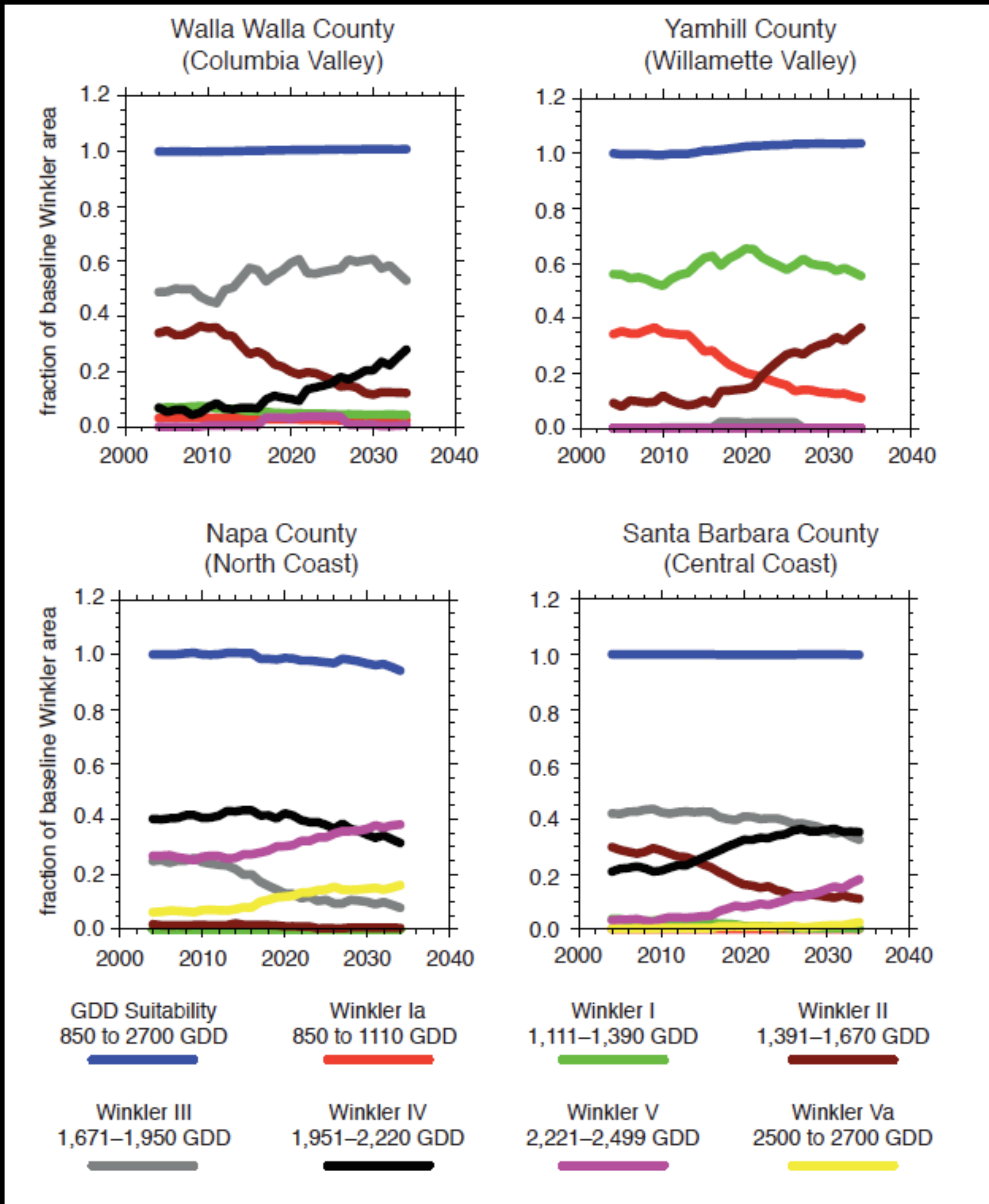
Diffenbaugh et al., ERL, 2011



Diffenbaugh et al., ERL, 2011

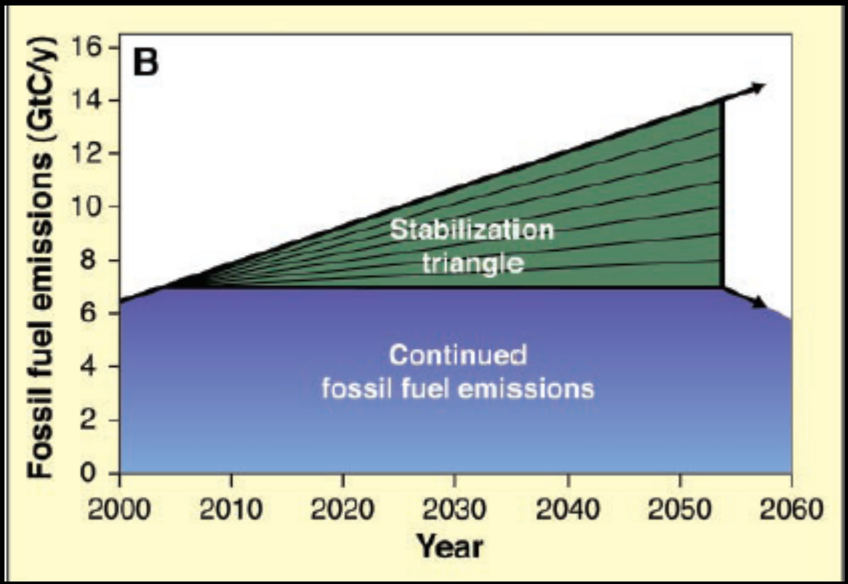


Diffenbaugh et al., ERL, 2011



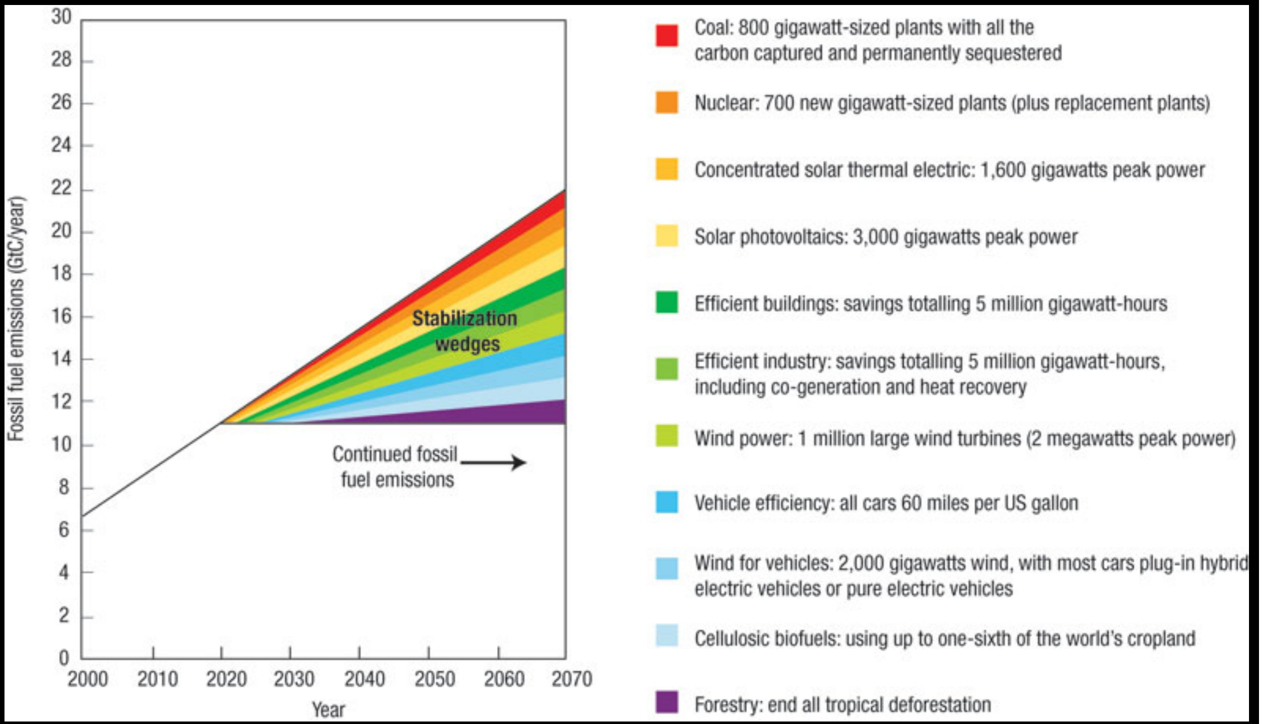
- potentially important changes in quality within suitability range

Diffenbaugh et al., ERL, 2011



Pacala and Socolow, 2004

Wedges?

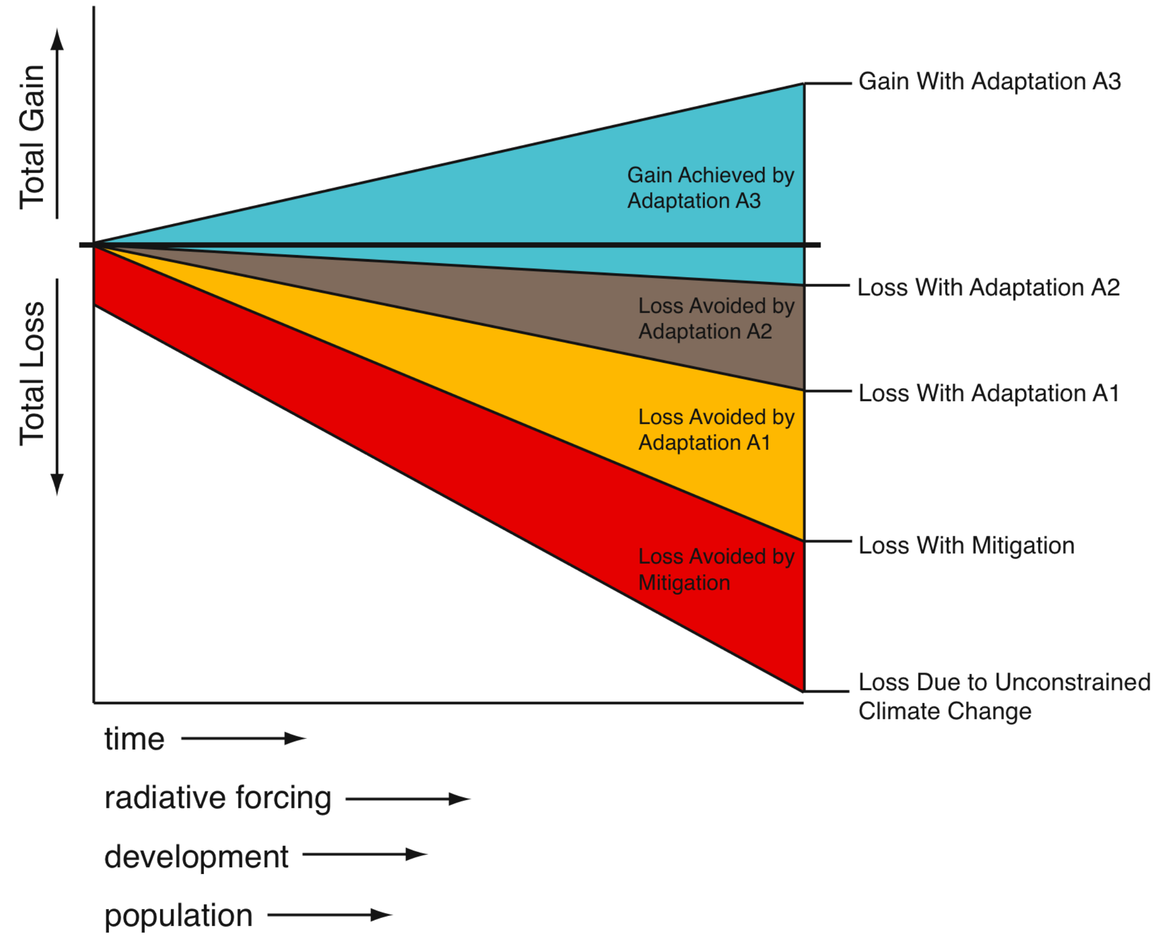


Romm, 2008

What is optimal combination of domains?

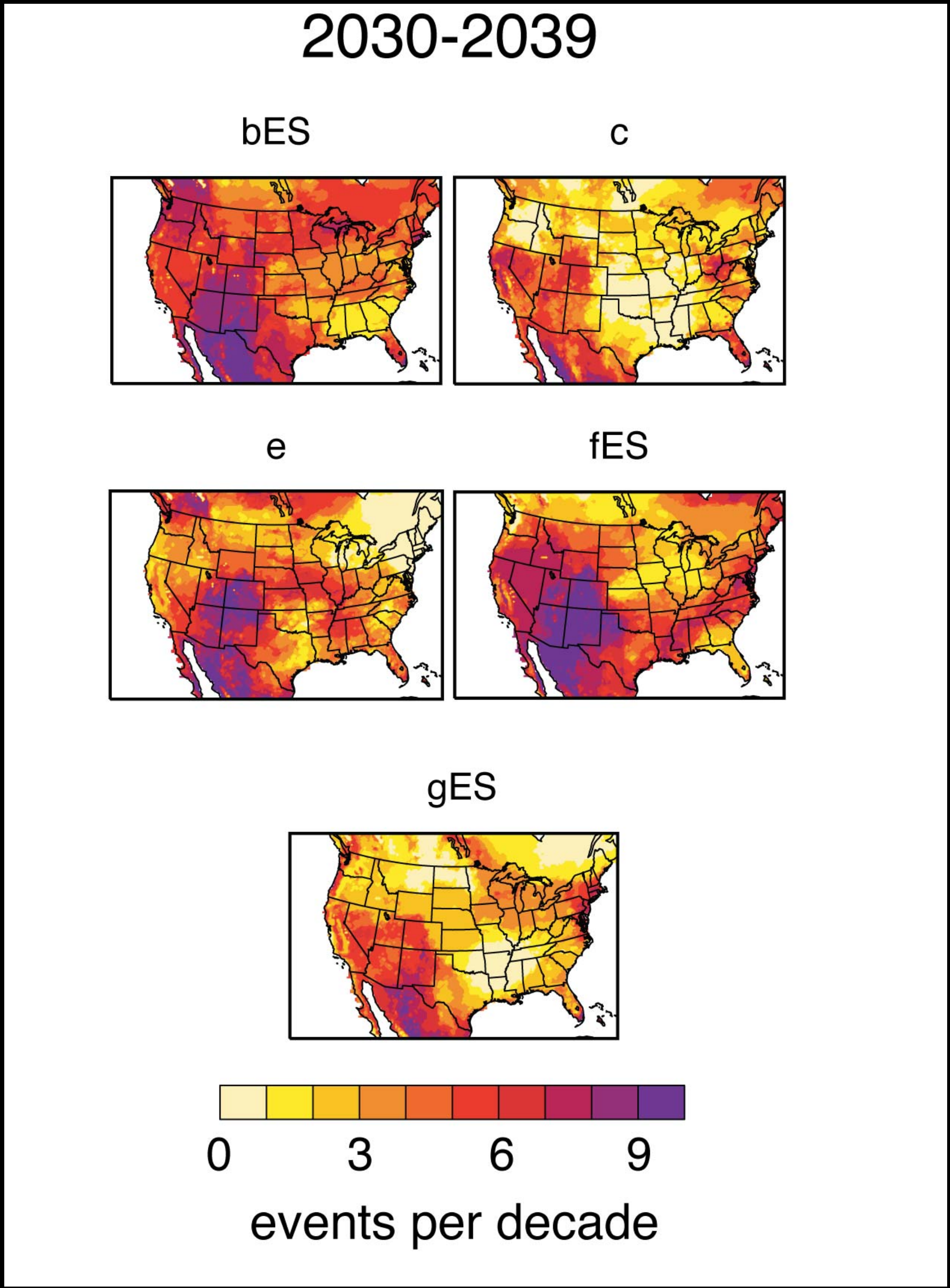
- Minimize total cost?
- Maximize total avoided damage?
- Maximize avoided damage/cost ratio?

- What is total cost of each domain?
- What is avoided damage of each domain?



Diffenbaugh et al., ERL, 2011

How Robust Is This Emergence?

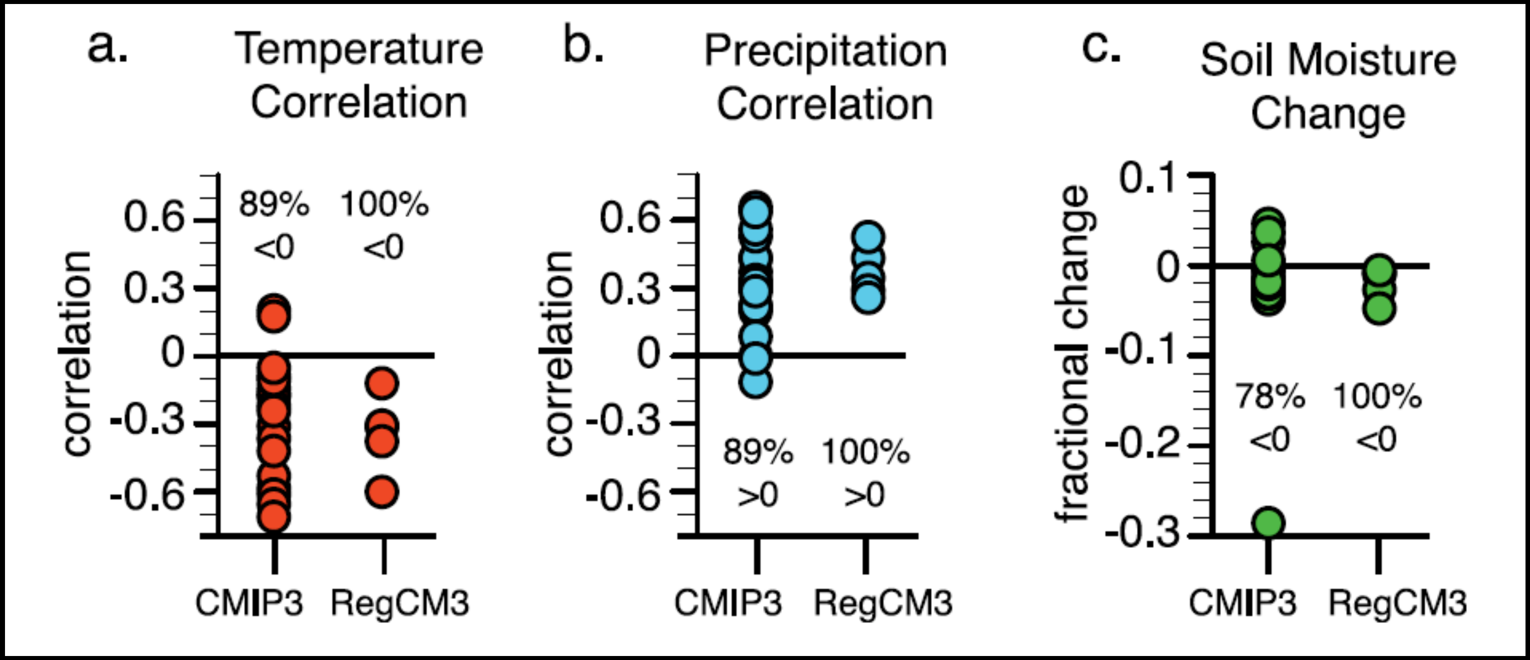


• Variation within "phyically uniform ensemble"

Diffenbaugh and Ashfaq, 2010

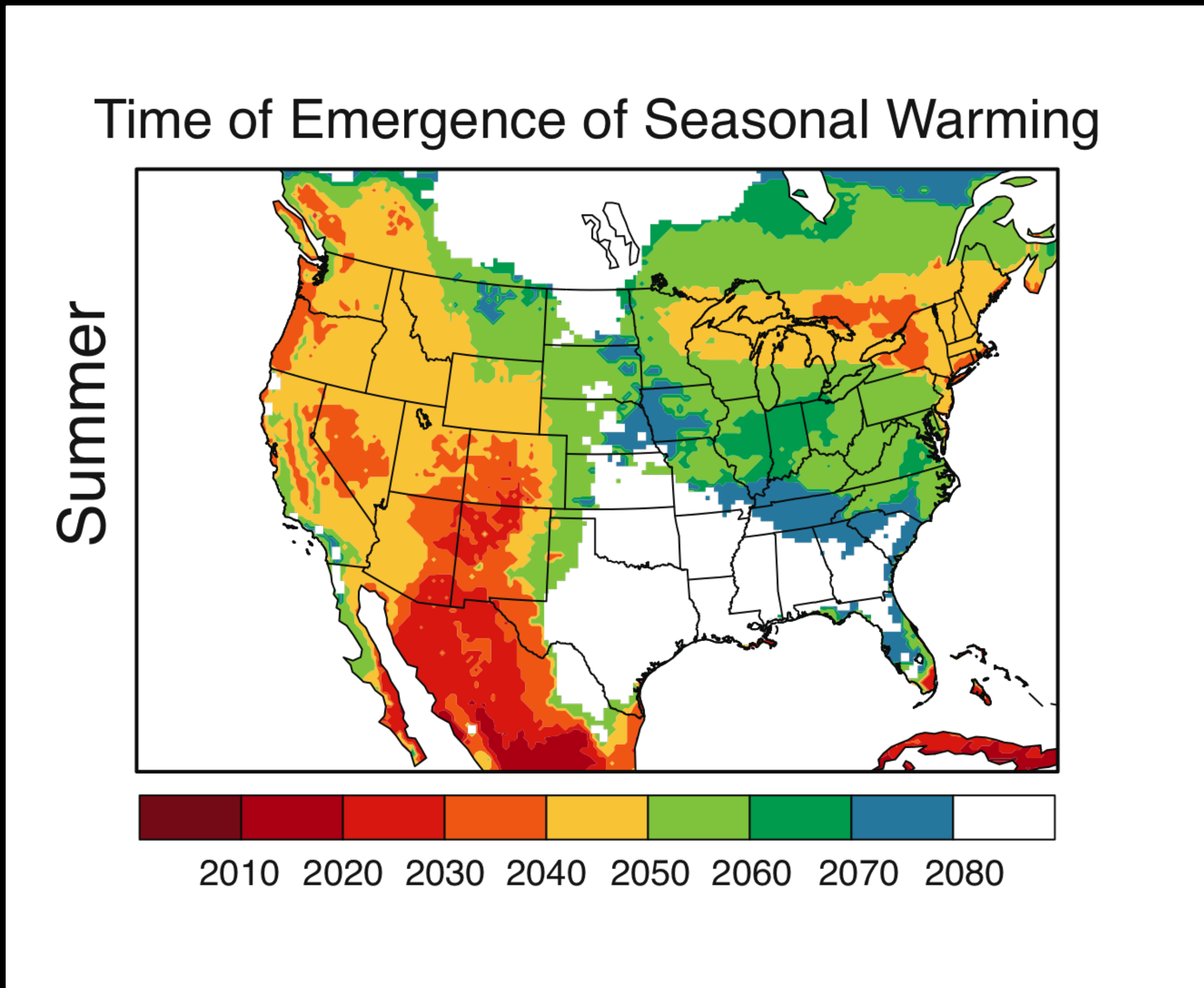
Summer Soil-Moisture/Temperature/ Precipitation Coupling

2030-2039 minus 1980-1999

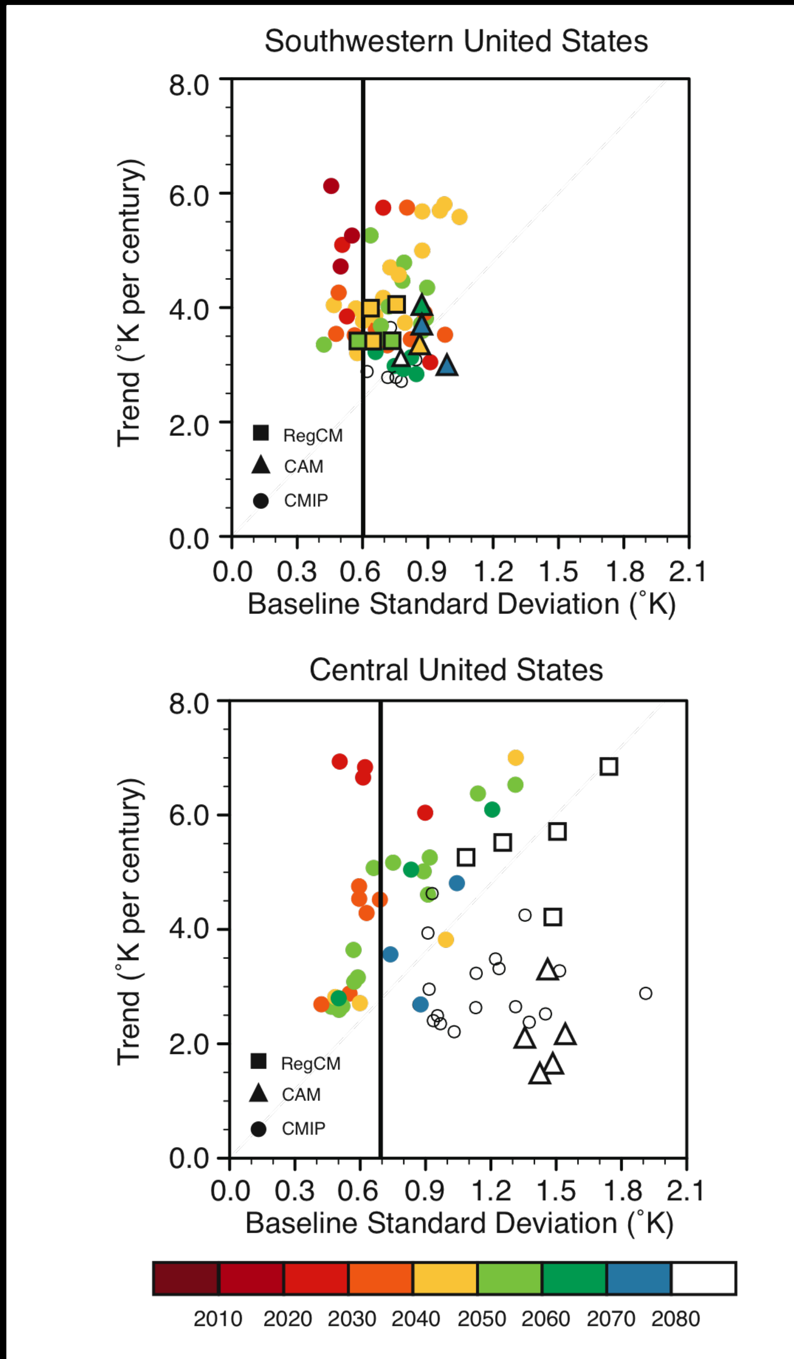


- Variation within “robust” physical response

Diffenbaugh and Ashfaq, 2010

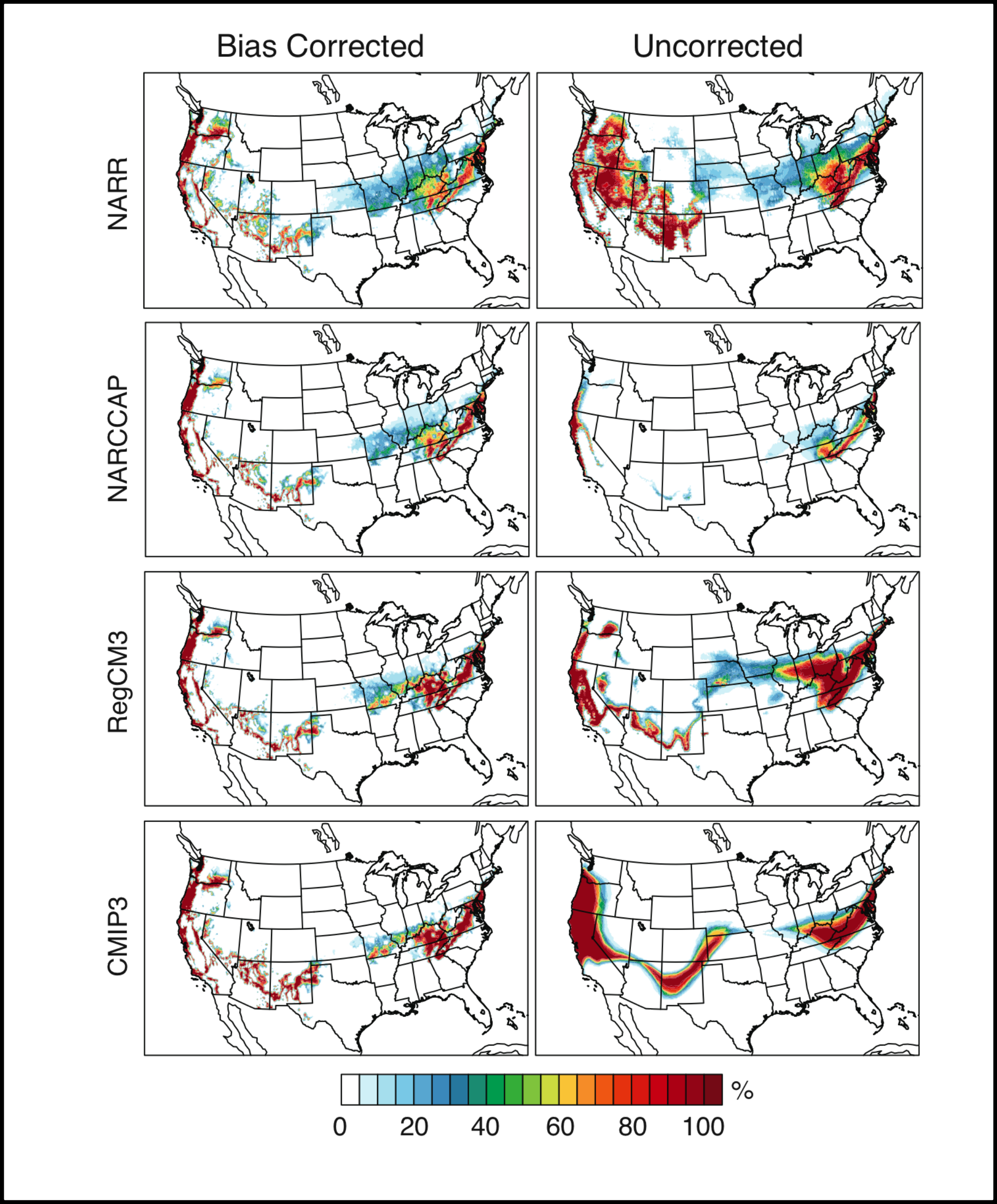


Diffenbaugh et al., JGR, in review



- Variation between models in both 21st century trend in mean and 20th century bias in variability

Diffenbaugh et al., JGR, in review

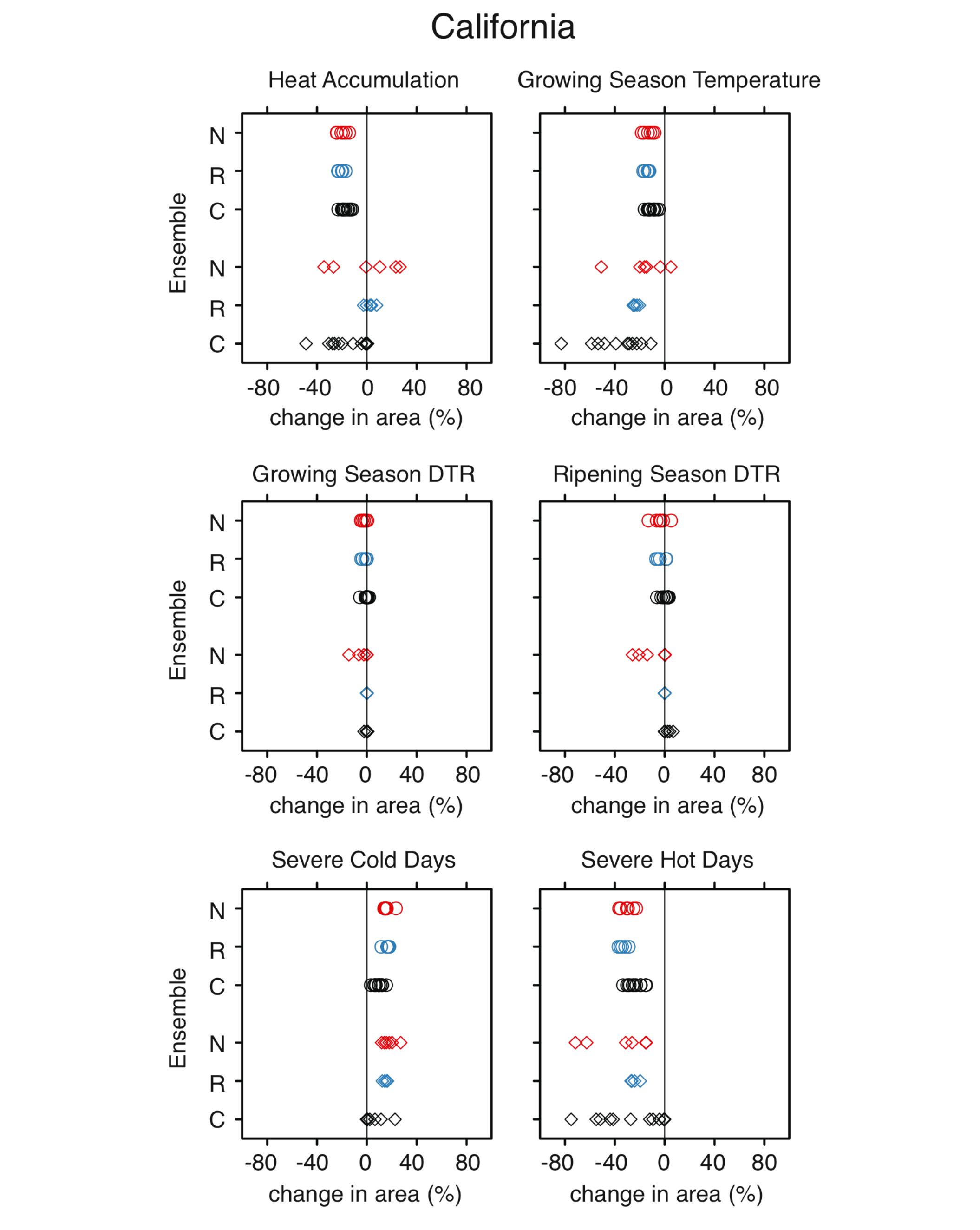


Premium Wine Suitability

- Bias correction reduces spread between model ensembles

(by construction for baseline)

Diffenbaugh and Scherer, in prep



- Bias correction reduces spread within and between model ensembles

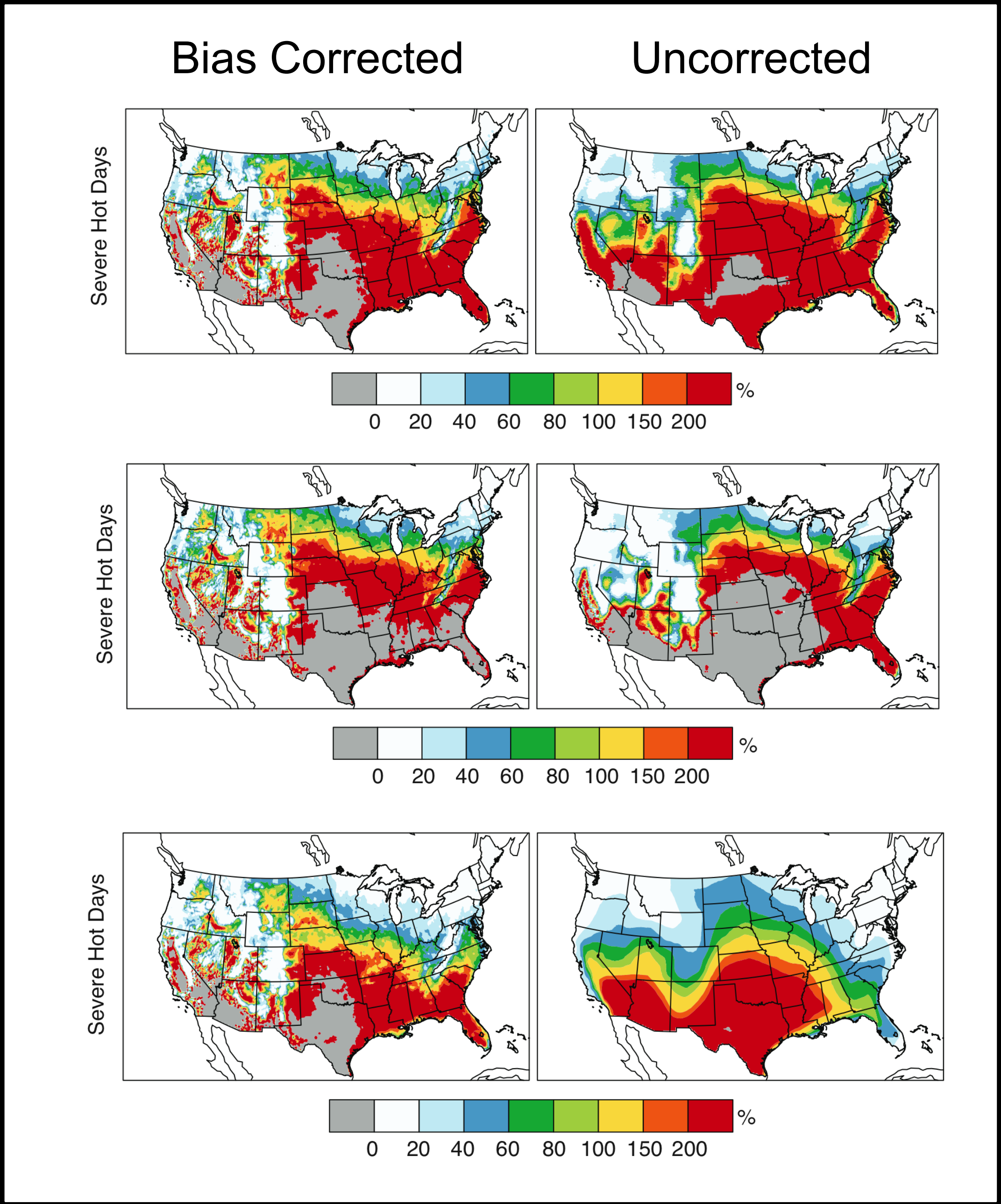
(although less for single-model ensemble)

Diffenbaugh and Scherer, in prep

NARCCAP

RegCM3

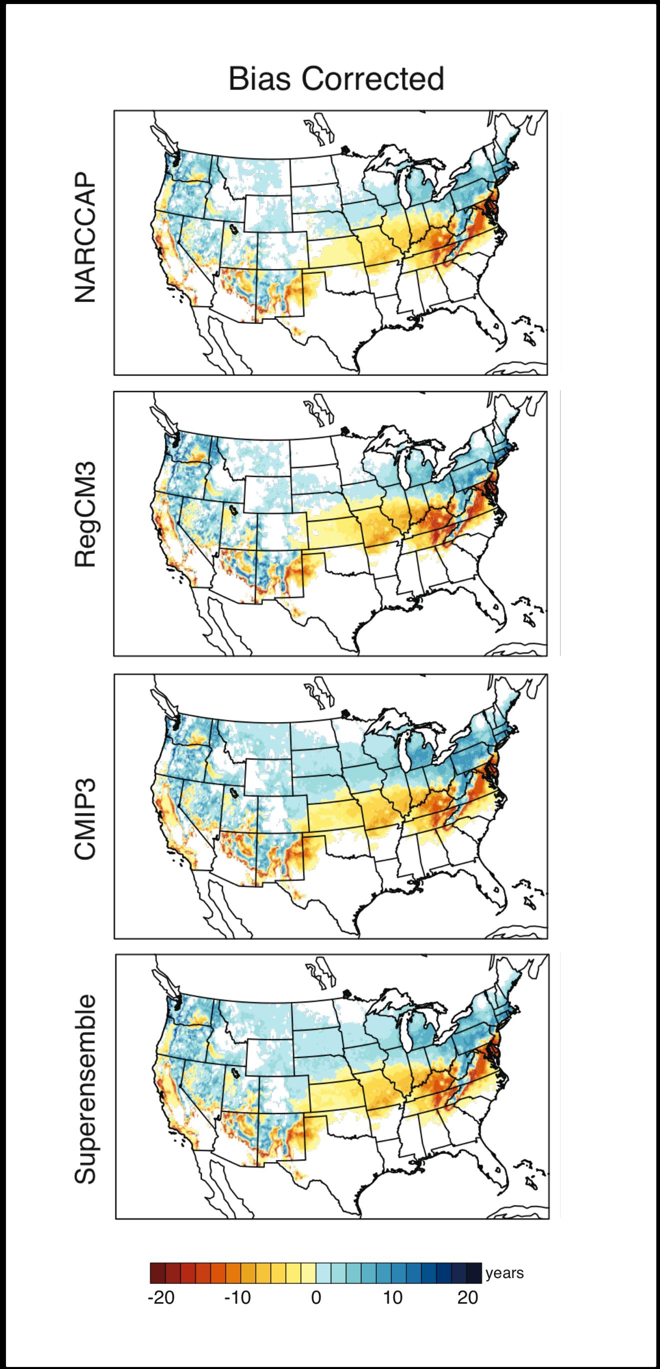
CMIP3



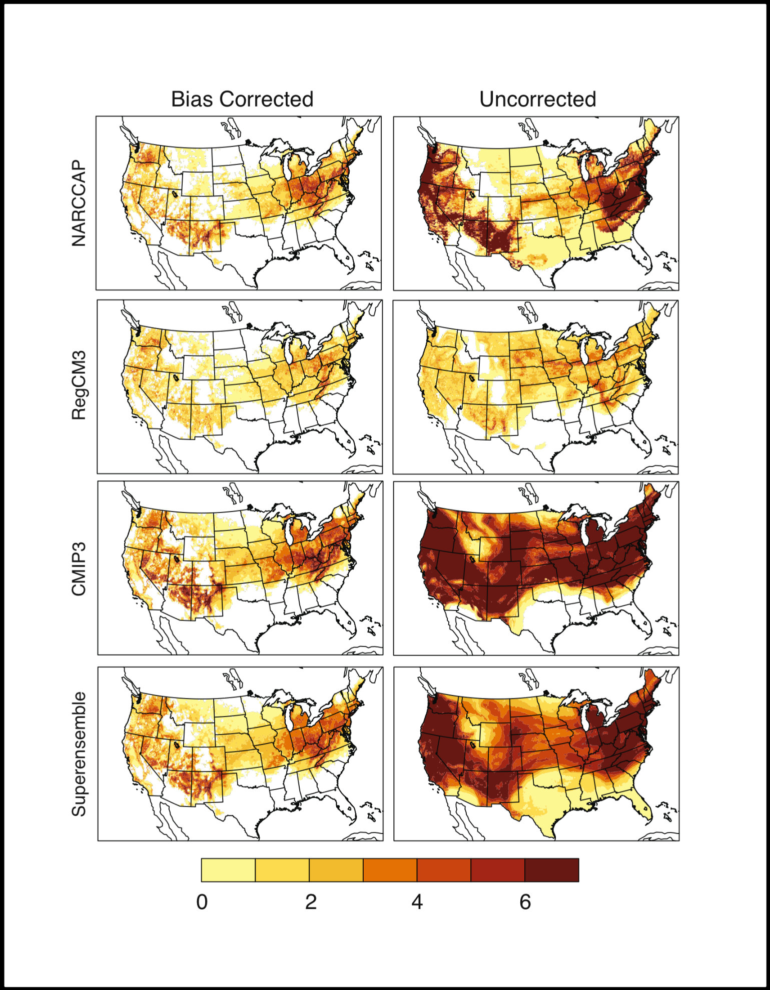
Change as % of "suitability margin"

Diffenbaugh and Scherer, in prep

Mid-21st Century Change



Intra-ensemble S.D.



Diffenbaugh and Scherer, in prep

What Does This All Mean For The E-L-W Nexus?

- Fine-scale climate processes can dictate
  - the magnitude and spatial variability of climate change,
  - where and at which levels of forcing critical thresholds are crossed,
  - and the magnitude and spatial variability of climate change impacts

- These processes can create substantial differences (in space and time) in impact and uncertainty

- Therefore, these fundamental climate dynamics must be integrated into policy frameworks in order to create effective interventions

- But… the near-term time scales and regional/local spatial scales that can be highly relevant for policy considerations can be at best difficult from a scientific perspective

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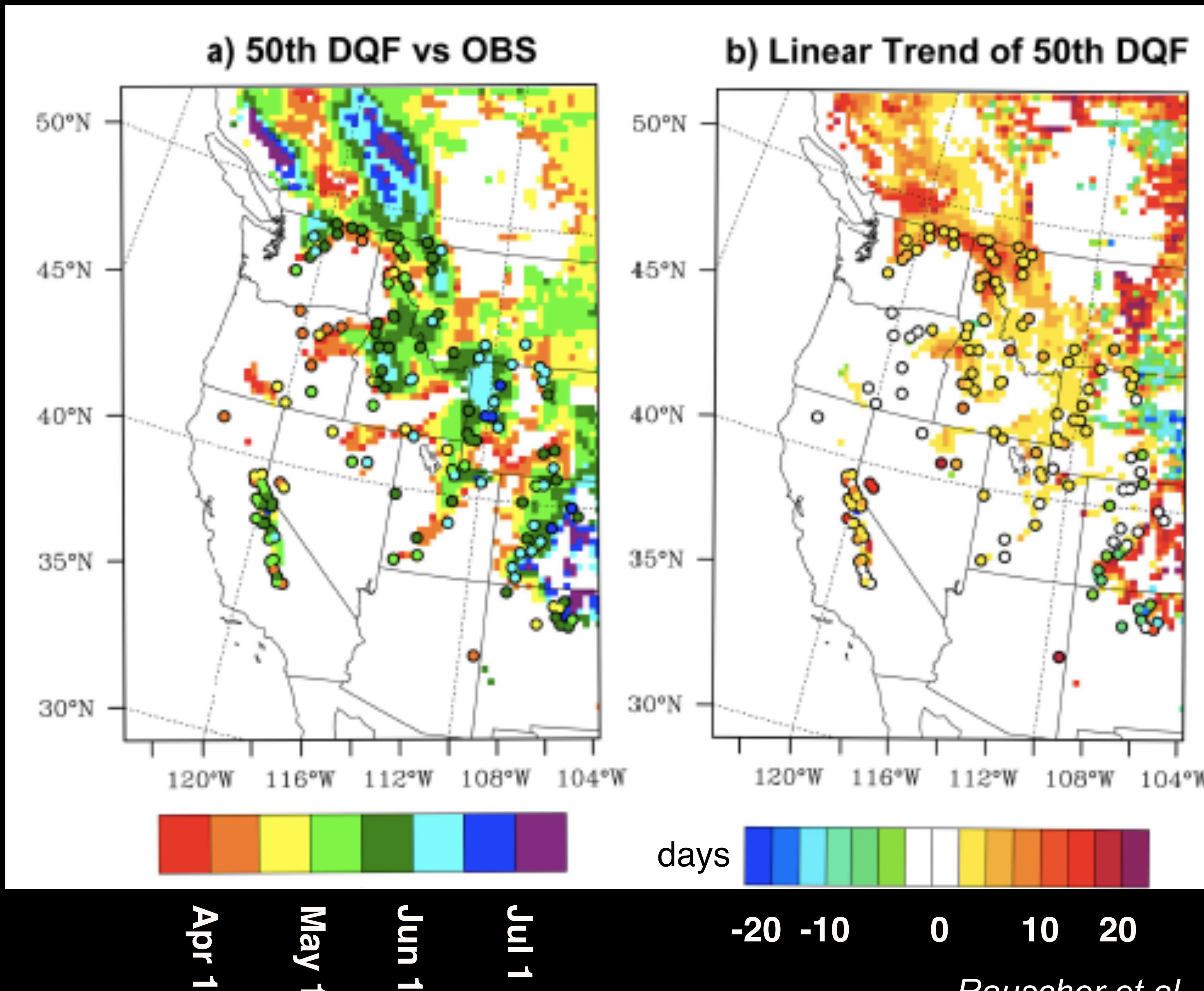
Snowmelt-Dominated Runoff



Rauscher et al., GRL, 2008