Past and future mysteries of climate science

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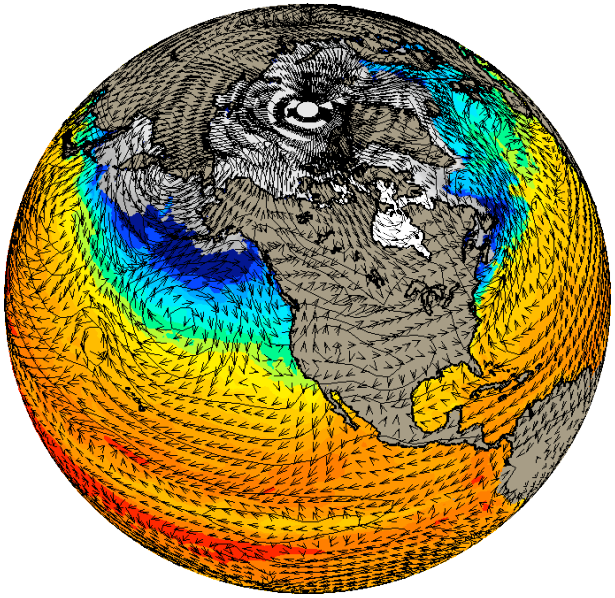


NCAR

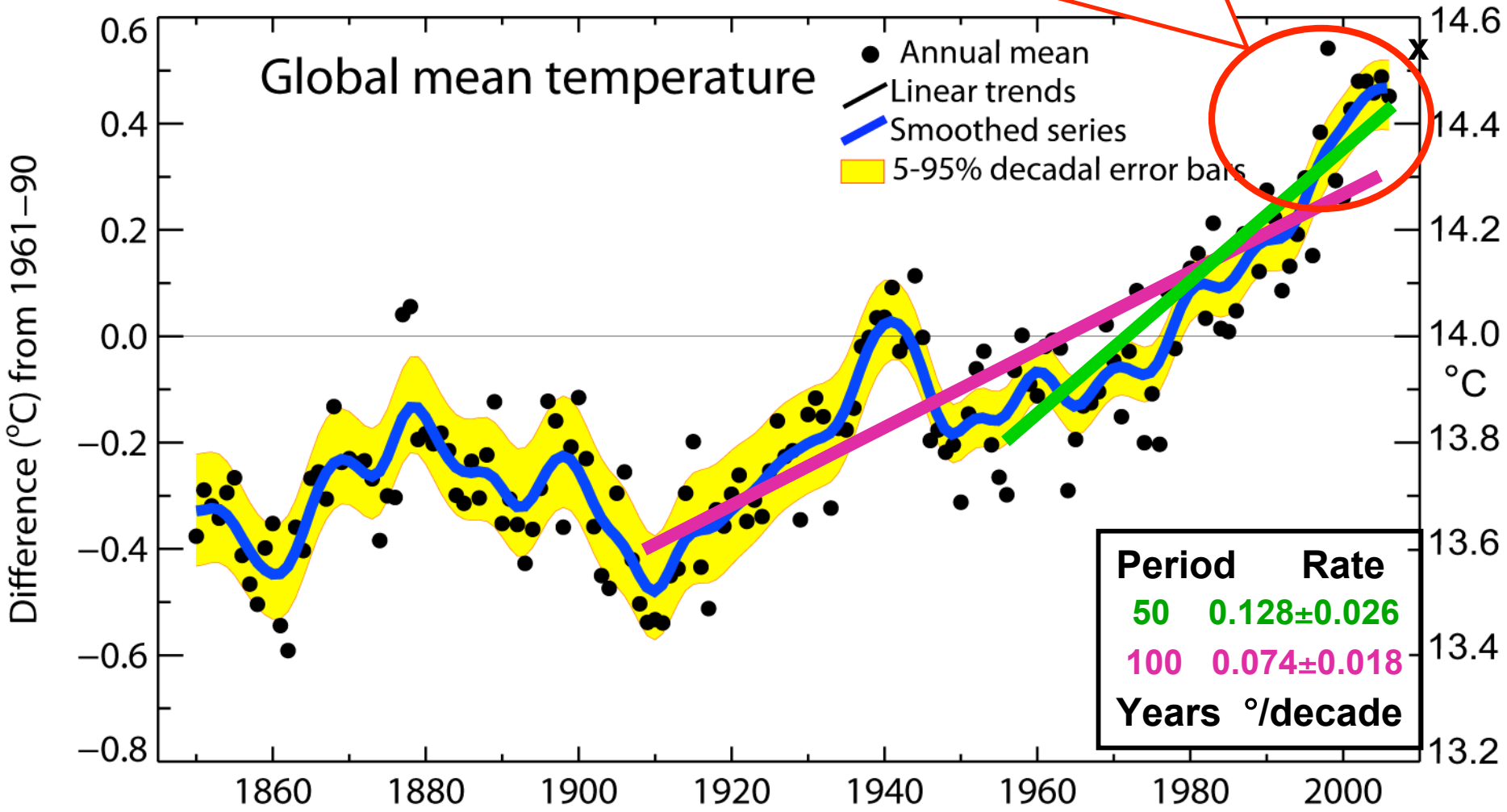
To understand the future, we must understand what happened during the 20th century.

So what's been happening?

12 of the last 13 years (1995-2007) rank among the 13 warmest years on record

Global mean temperat… …time

Warmest 13 years: 2007, 1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995, 1999, 1990, 2000



Upsala glacier in the Andes, Argentina

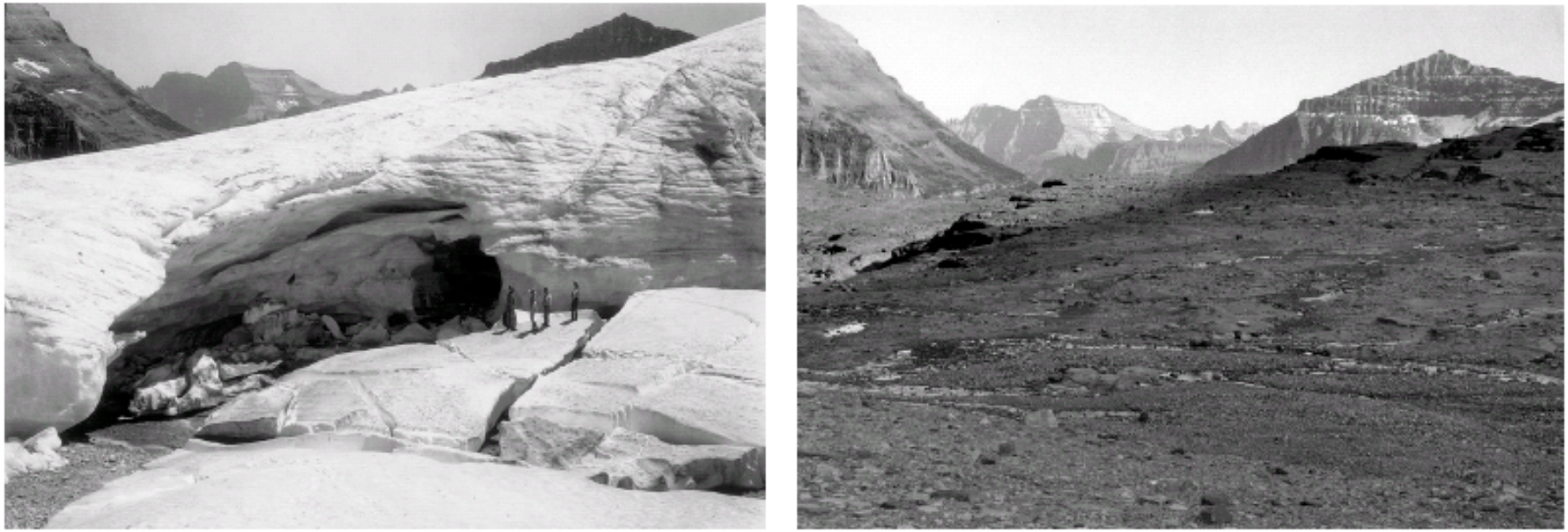
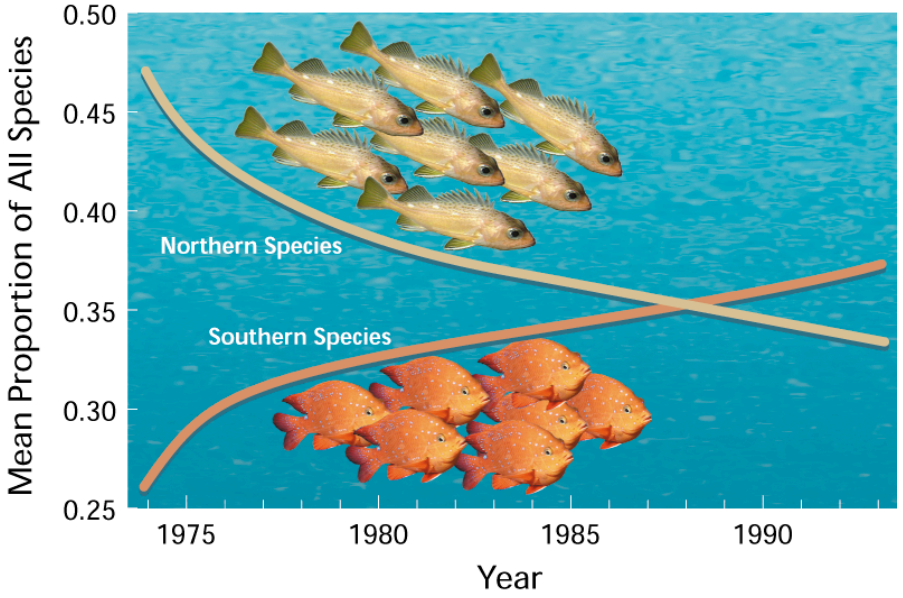


Figure 5. Boulder Glacier: 1932 (left), 1988 (right). These two views of Boulder Glacier demonstrate the dramatic reduction in ice in Glacier National Park and its ecological consequences. Vegetation has moved in where the ice cave used to be. Photographs: 1932, George Grant, courtesy of Glacier National Park archives; 1988, Jerry DeSanto, National Park Service.

Altered range limits

- Average change in “cold” limit:
  4 miles/decade North or
  20’ higher/decade
  - 99 species (plants, birds, & butterflies)

- 81% of range changes in expected direction
  - 372 species (trees, shrubs, herbs, birds, mammals, reptiles, amphibians, fish, insects, & marine invertebrates)



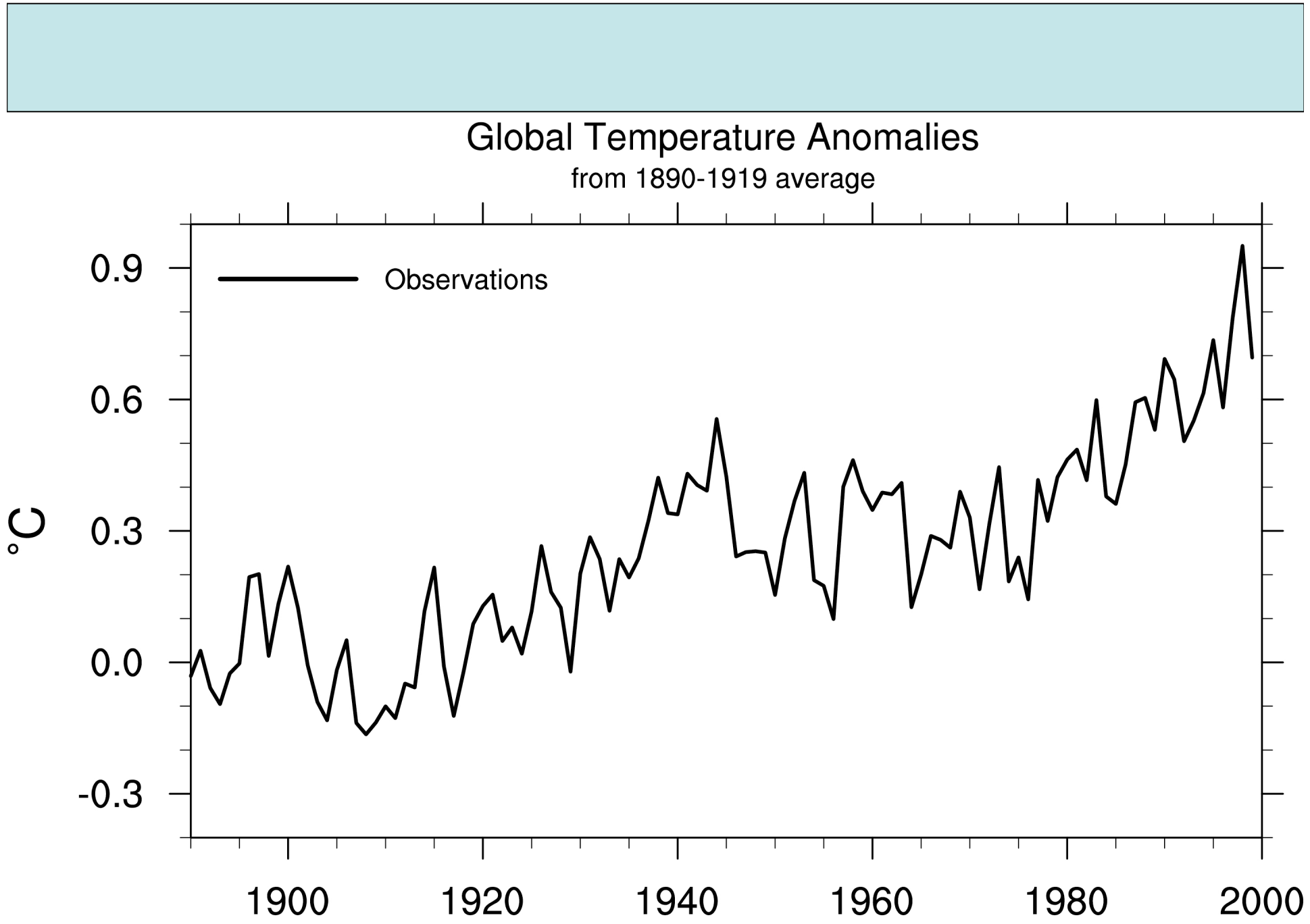
"Warming of the climate system is unequivocal"

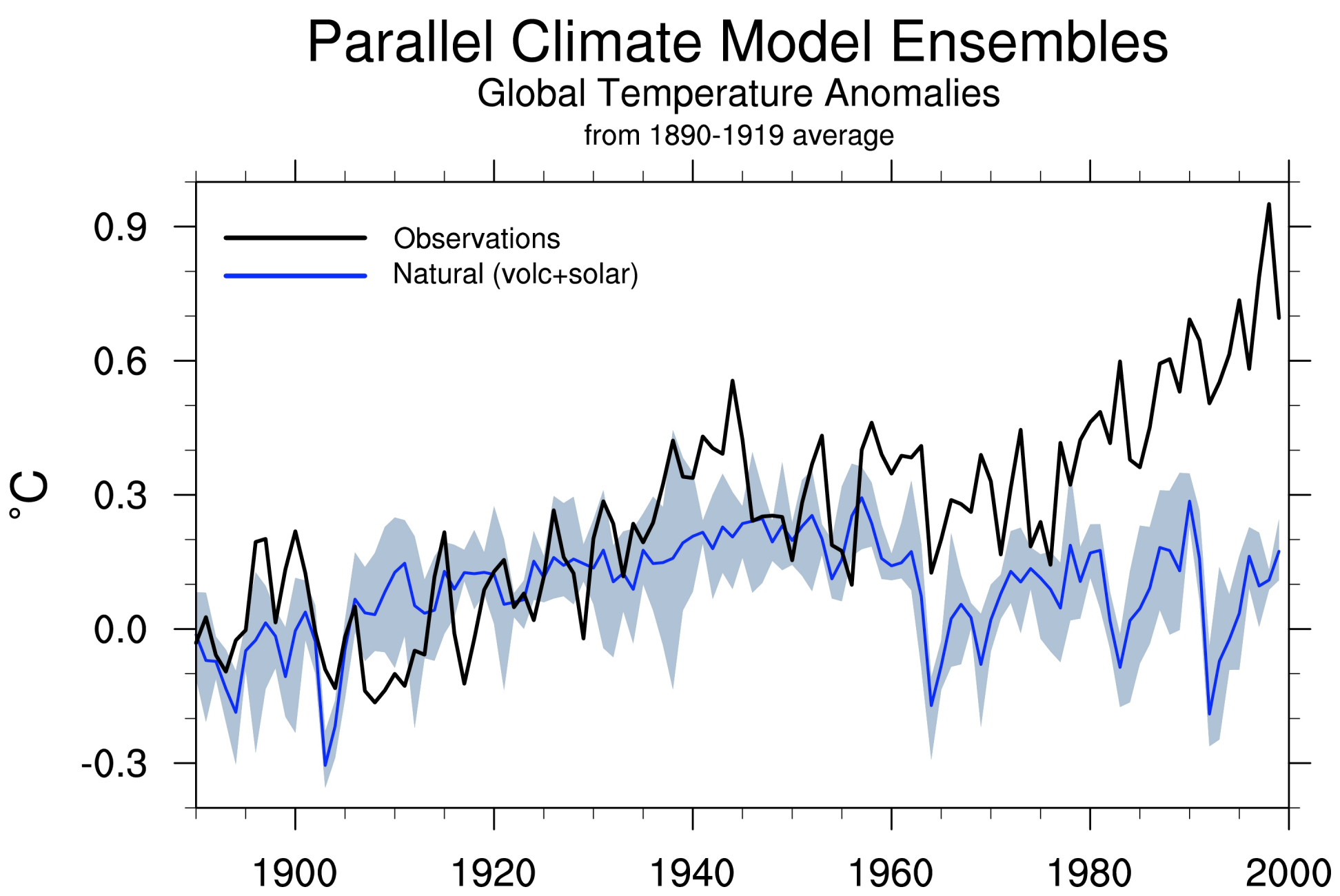
---IPCC Fourth Assessment Report, 2007

So the climate has been warming, but have humans had anything to do with it?

A major mystery is why the globally averaged surface air temperatures did not warm monotonically even though human-produced greenhouse gases were increasing the whole time

We can use climate models to address this mystery …


Global Temperature Anomalies
from 1890-1919 average
Observations
°C
0.9
0.6
0.3
0.0
-0.3
1900
1920
1940
1960
1980
2000


Parallel Climate Model Ensembles
Global Temperature Anomalies
from 1890-1919 average
Observations
Natural (volc+solar)
°C
0.9
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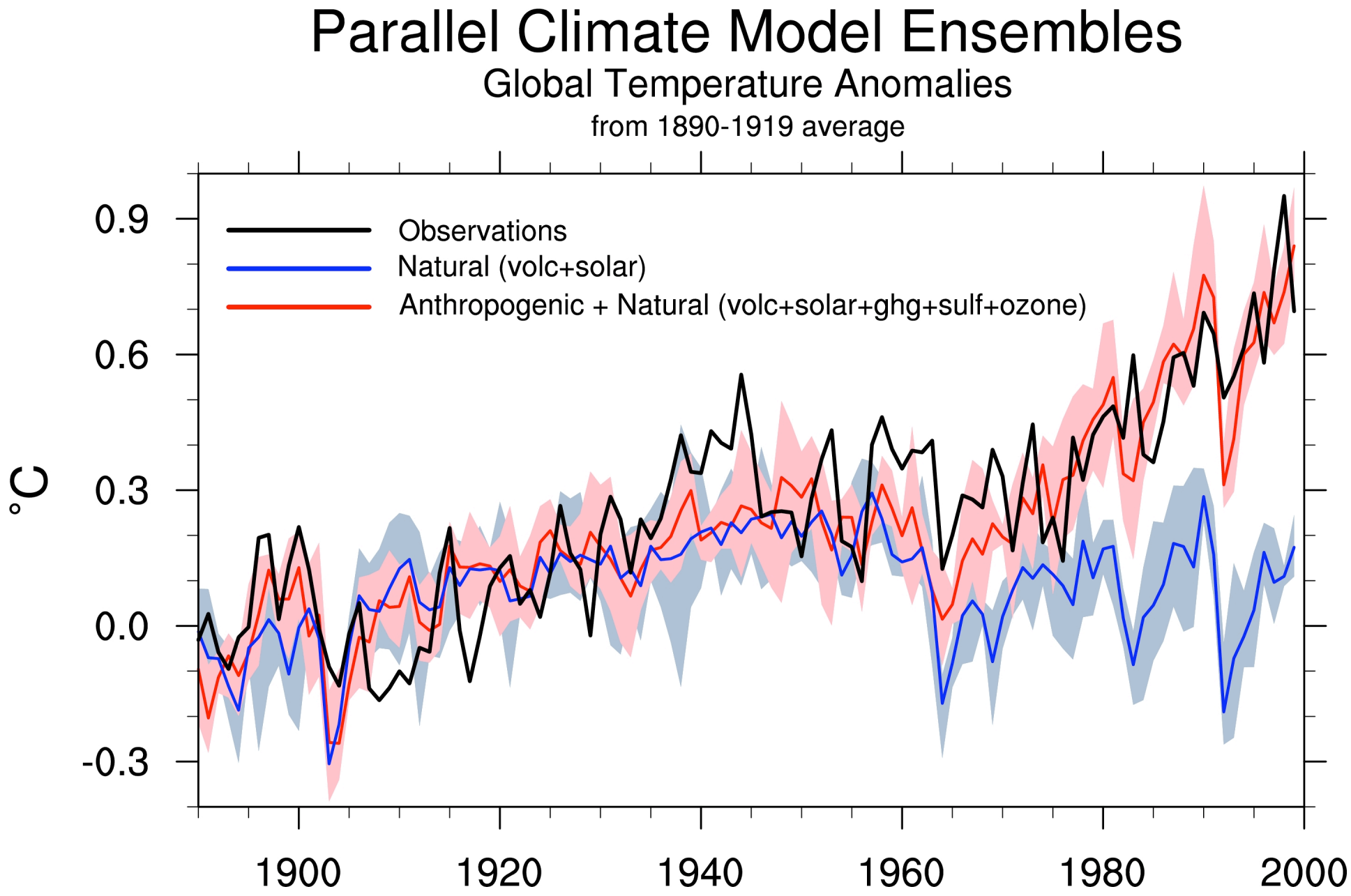
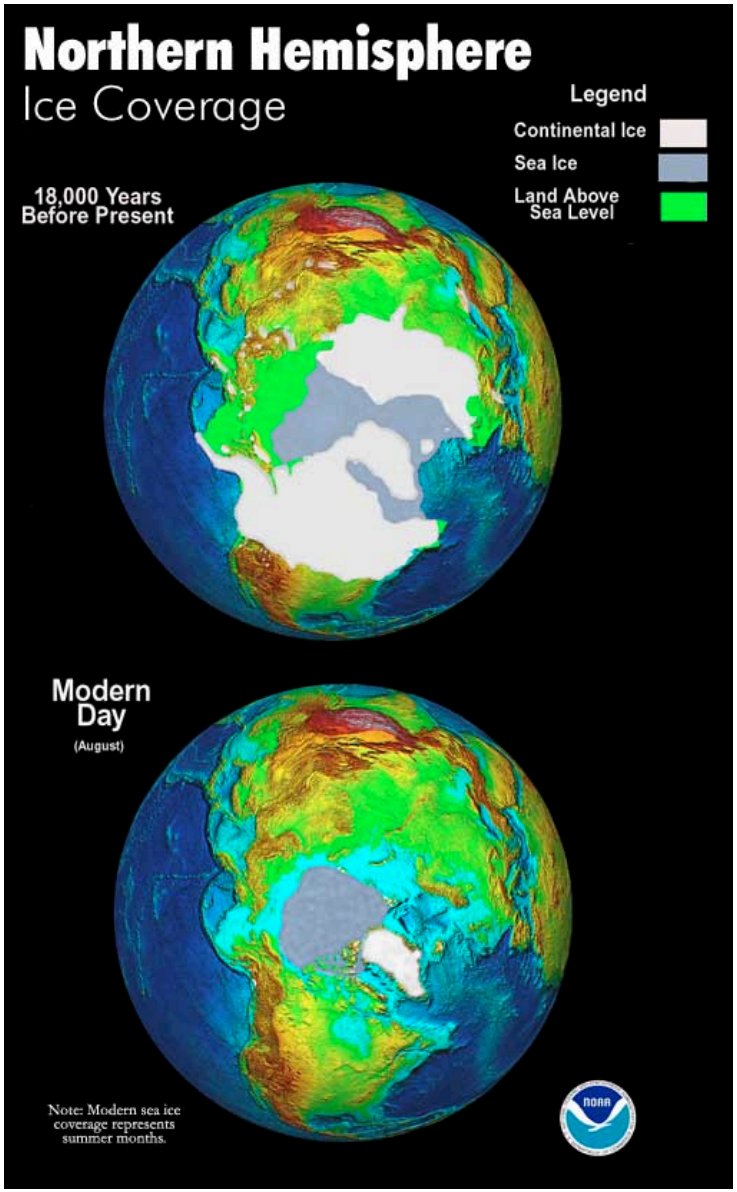
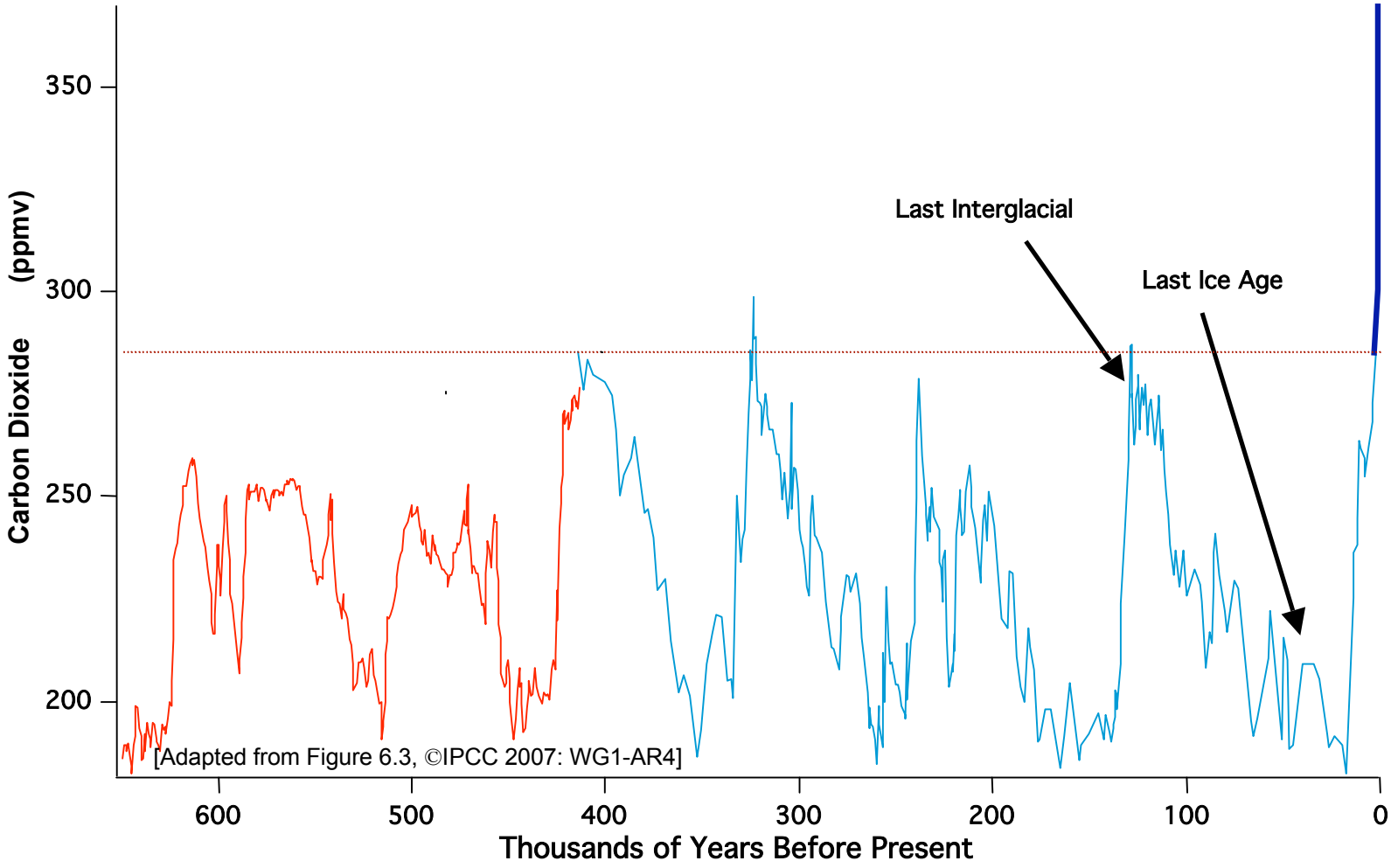

Parallel Climate Model Ensembles
Global Temperature Anomalies
from 1890-1919 average
Observations
Natural (volc+solar)
Anthropogenic + Natural (volc+solar+ghg+sulf+ozone)
°C
0.9
0.6
0.3
0.0
-0.3
1900
1920
1940
1960
1980
2000

What about natural climate cycles? Are the current conditions really unusual?



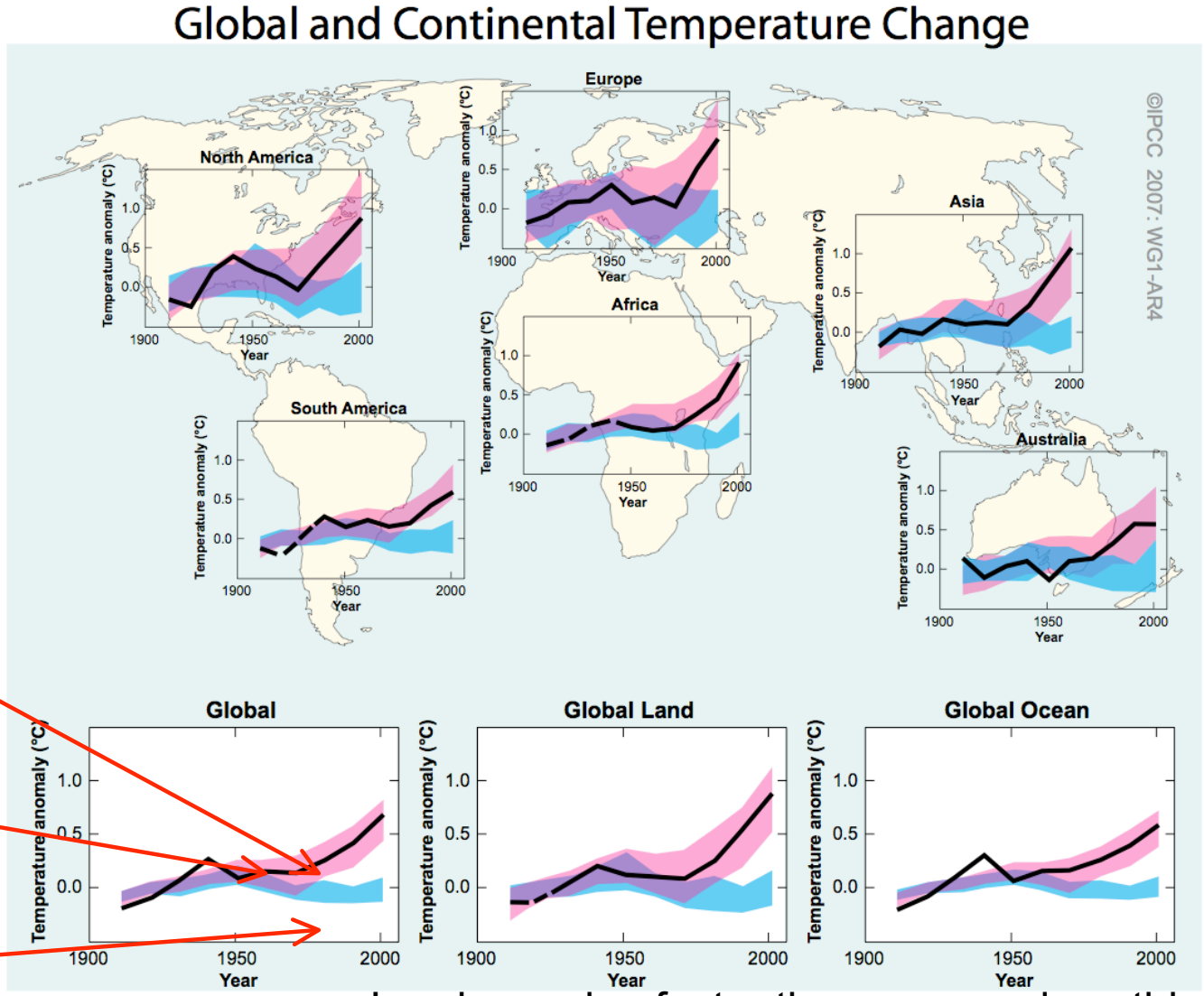


Ice ages are not random. They are 'forced' (by earth's orbital clock…. changes in the sunlight received).

Humans are 'forcing' the system in a new way. CO_2 increases are mainly due to fossil fuel burning. CO_2 has not been this high in more than half a million years.

What about future climate change mysteries? How much warming are already committed to, and how may that relate to overall warming in the future?

IPCC AR4: "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

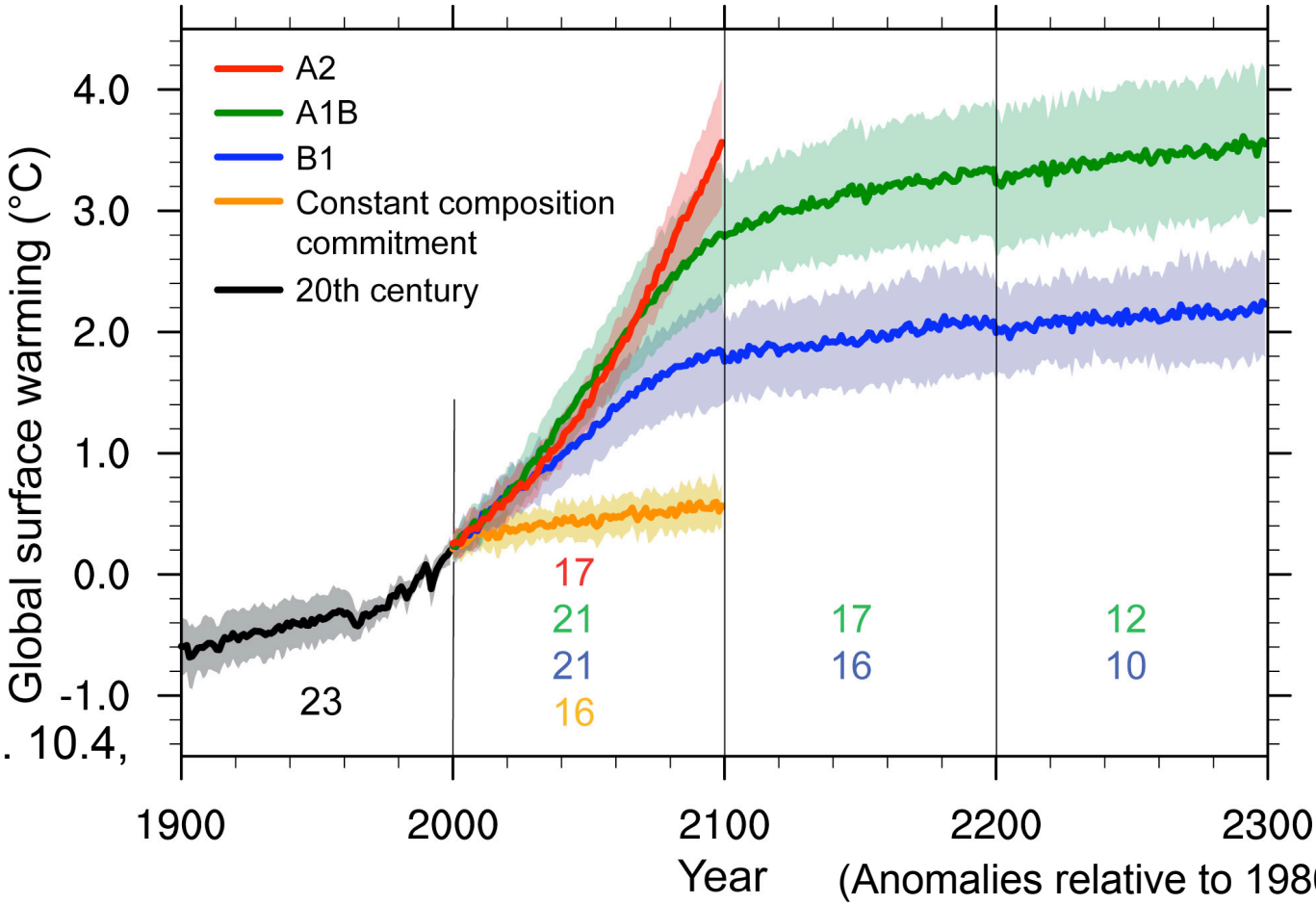


Observed

Expected for all forcings

Natural forcing only

Land warming faster than ocean; does this imply a commitment to further warming?



Ch. 10, Fig. 10.4, TS-32

Unprecedented coordinated climate change experiments from 16 groups (11 countries) and 23 models collected at PCMDI (31 terabytes of model data), openly available, accessed by over 1200 scientists; over 200 papers

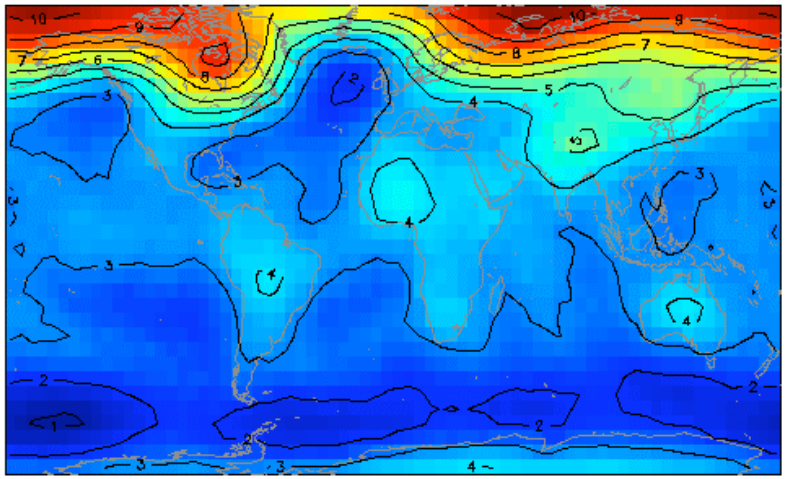
Committed warming averages 0.1°C per decade for the first two decades of the 21st century; across all scenarios, the average warming is 0.2°C per decade for that time period (recent observed trend 0.2°C per decade)

What about regional climate change? Is there any way to get probabilistic information?

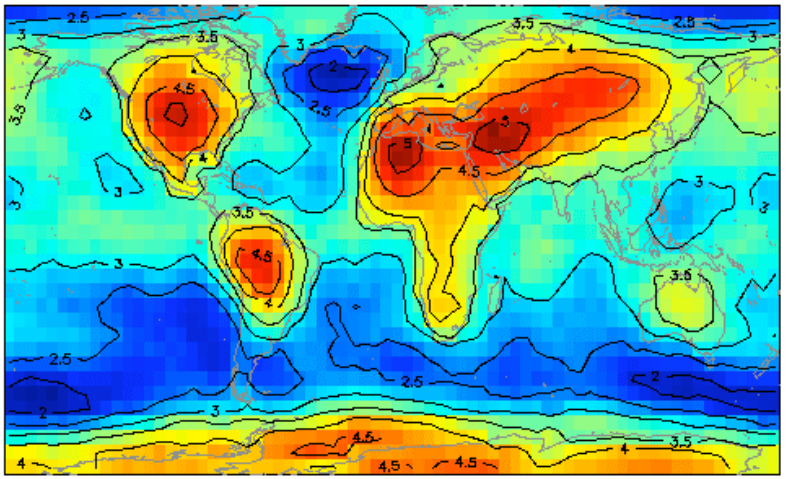
With the CMIP3 multi-model dataset, probabilistic climate change is being addressed for the first time

(Furrer et al., 2007 and IPCC AR4 2007)

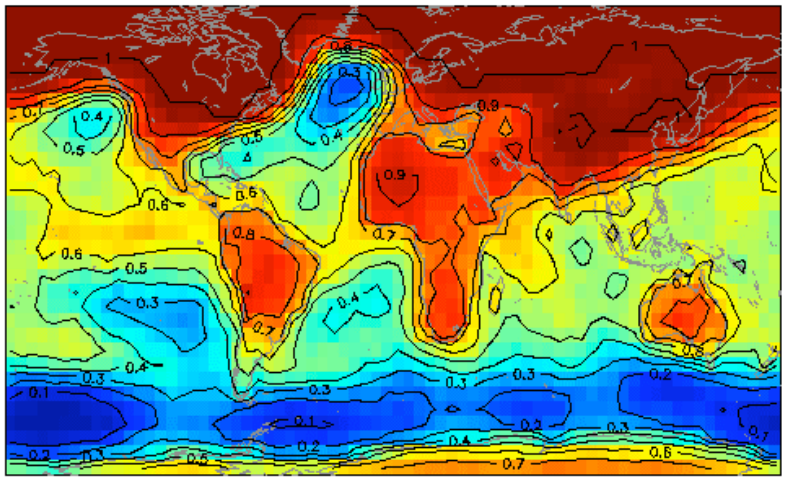
Highest possible DJF temperature change occurring with 80% probability (A1B)



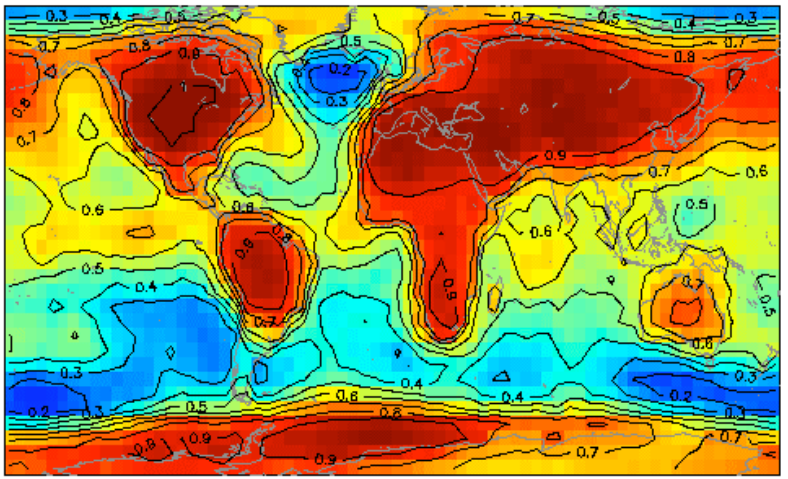
Highest possible JJA temperature change occurring with 80% probability (A1B)



Probability that DJF temperature exceeds 2 degrees C (A1B)



Probability that JJA temperature exceeds 2 degrees C (A1B)

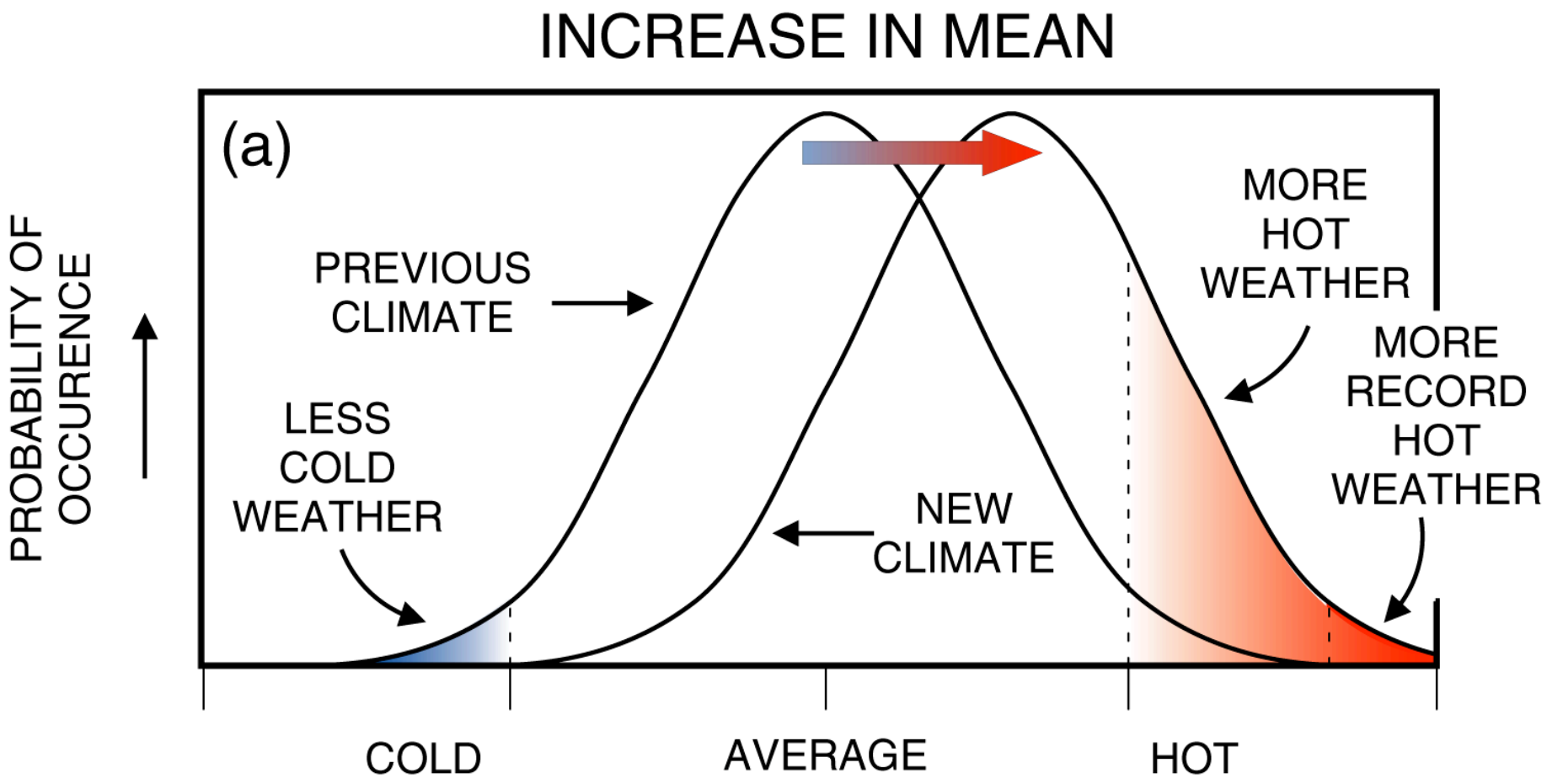


What about weather and climate extremes?

Extremes often produce the greatest impacts on human society and ecosystems

Extremes are usually defined with respect to specific impacts

The physical processes that produce extremes are highly relevant to their impacts


INCREASE IN MEAN
(a)
PROBABILITY OF OCCURENCE
PREVIOUS CLIMATE
LESS COLD WEATHER
NEW CLIMATE
MORE HOT WEATHER
MORE RECORD HOT WEATHER
COLD
AVERAGE
HOT

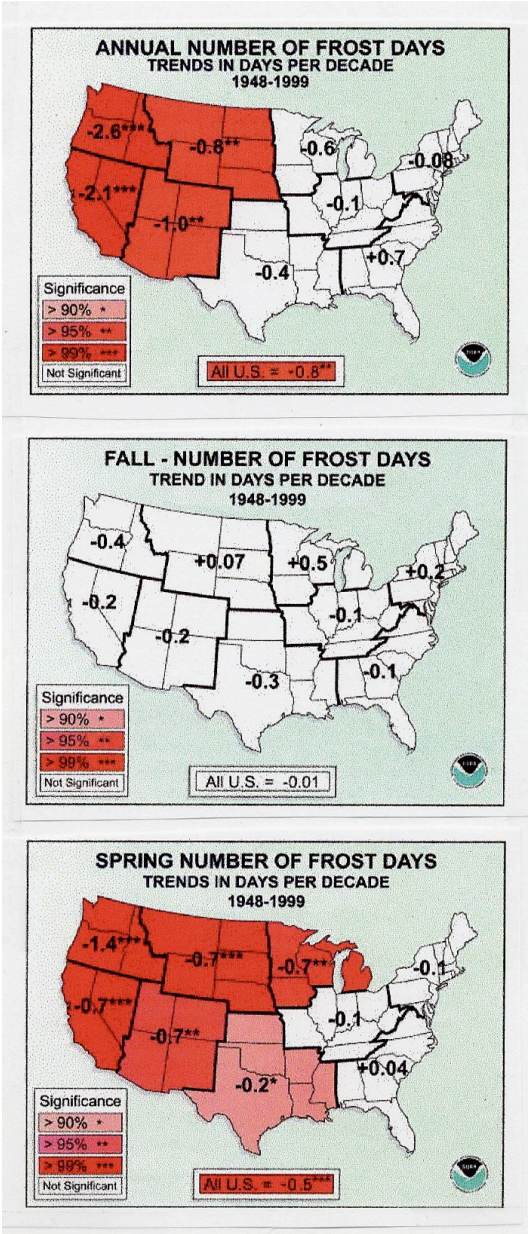
Impacts on Agricultural and Biological Systems related to Frost Days

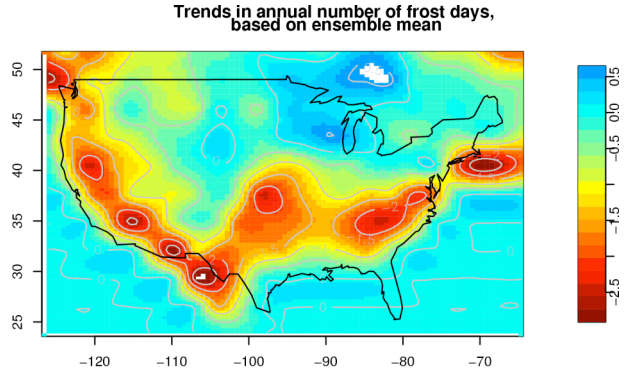
(Meehl, Tebaldi and Nychka, 2004: Changes in frost days in simulations of twentyfirst century *Climate Dynamics*, 23, 495--511)

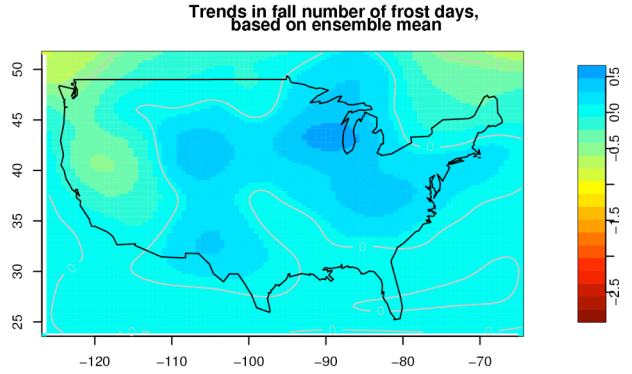
Changes in frost days affect:

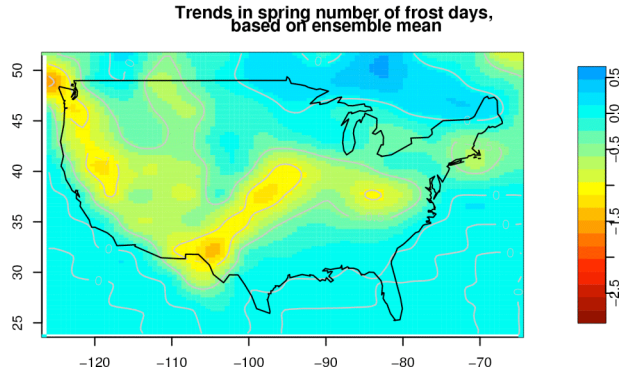
- Range shifts (latitudinal or altitudinal)
- Change in growing season length
- Water resources (change in snow melt season)
- Earlier flowering; emergence of insects; earlier mating; loss of habitat, shorter hibernation

Changes in frost days in the late 20th century show biggest decreases over the western and southwestern U.S. in observations and the model

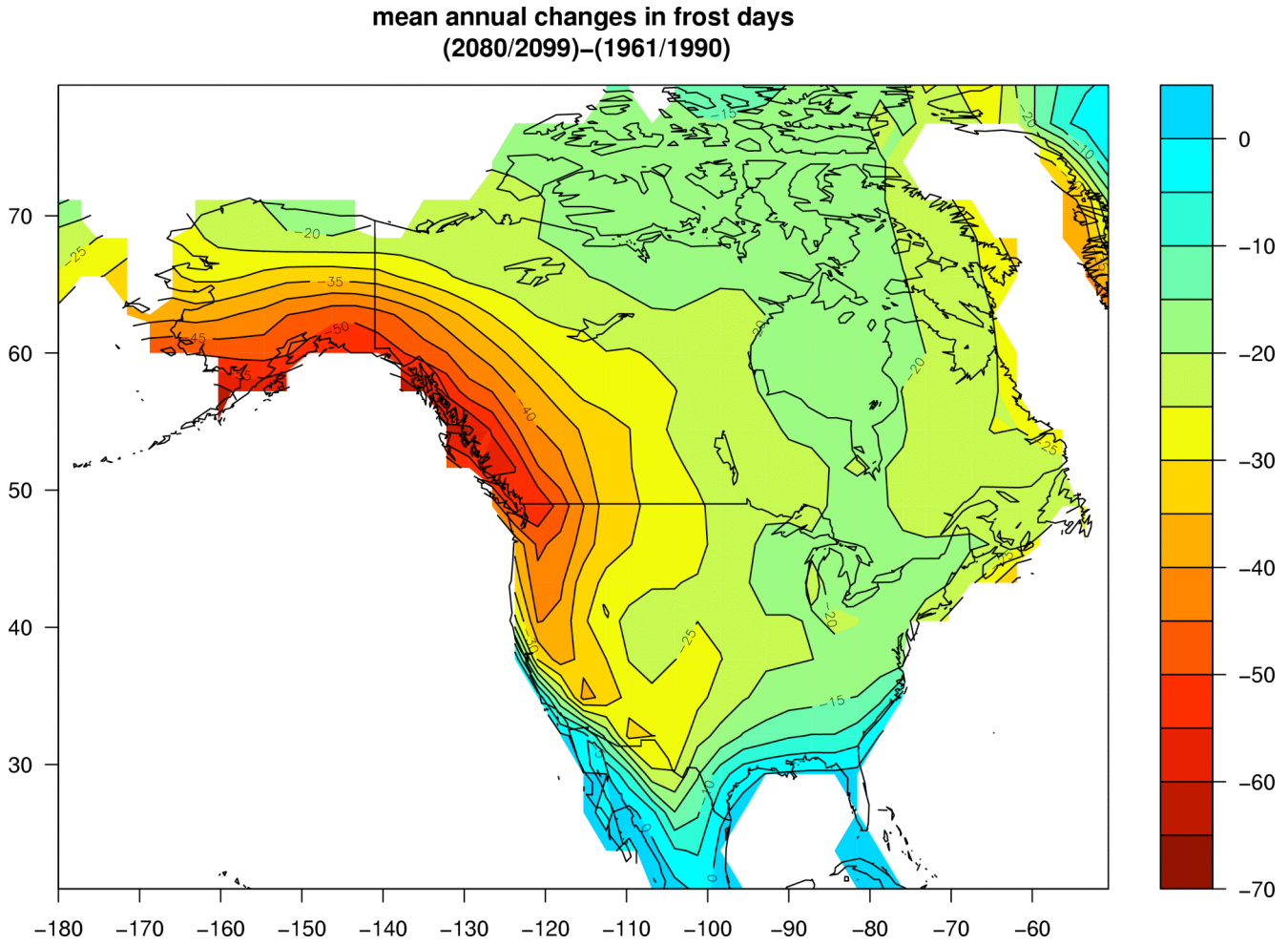








Future changes in frost days from the climate model show greatest decreases in the western and southwestern U.S., similar to late 20th century



Heat Waves

Impacts on human health and mortality, economic impacts, ecosystem and wildlife impacts

(Meehl and Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century, *Science*, 305, 994-997)

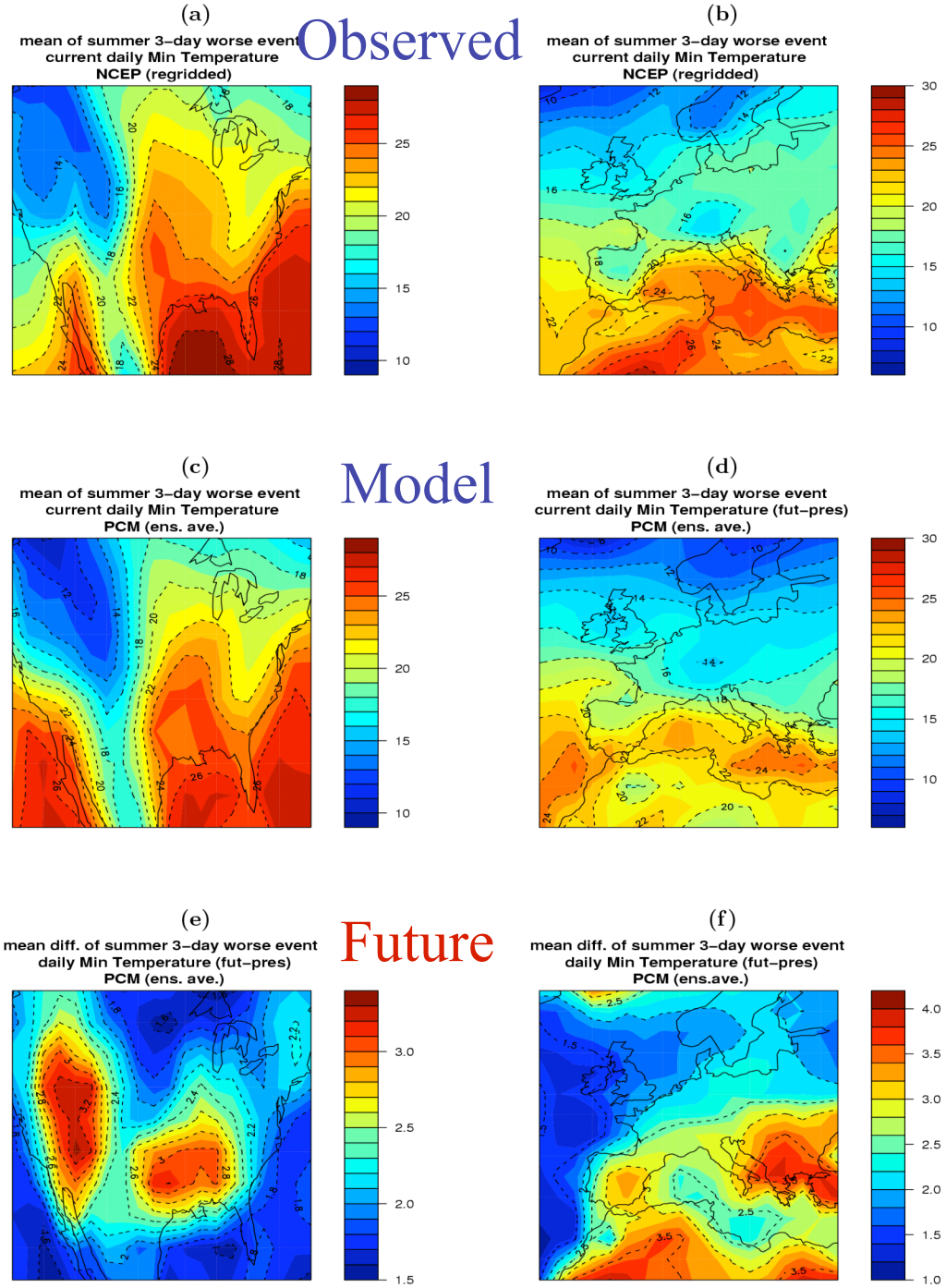
Climate models can be used to provide information on changes in extreme events such as heat waves

Heat wave severity defined as the mean annual 3-day warmest nighttime minima event

Model compares favorably with present-day heat wave severity

In a future warmer climate, heat waves become more severe in southern and western North America, and in the western European and Mediterranean region

Meehl, G.A., and C. Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century. *Science*, **305**, 994--997.



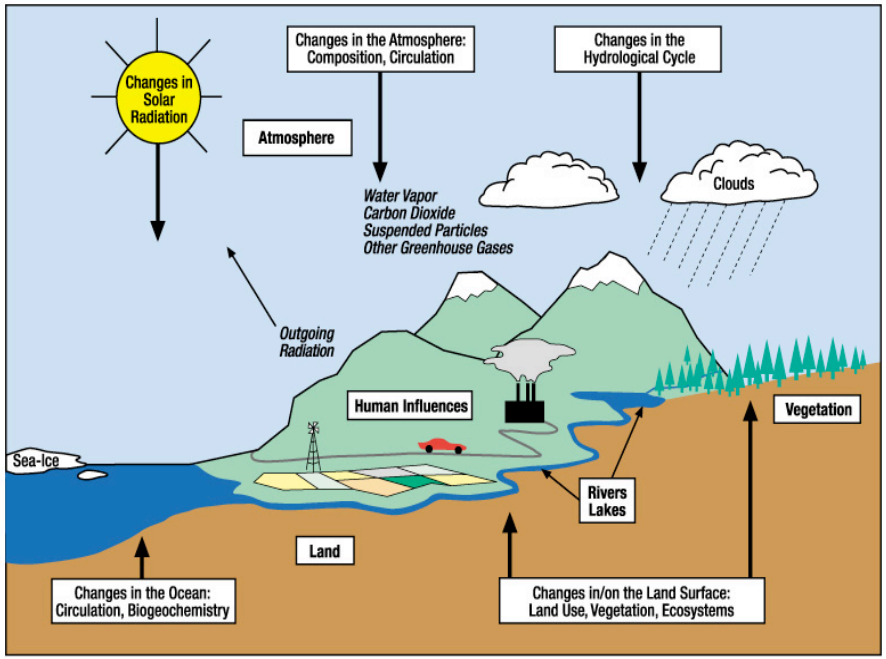
The warmer future:

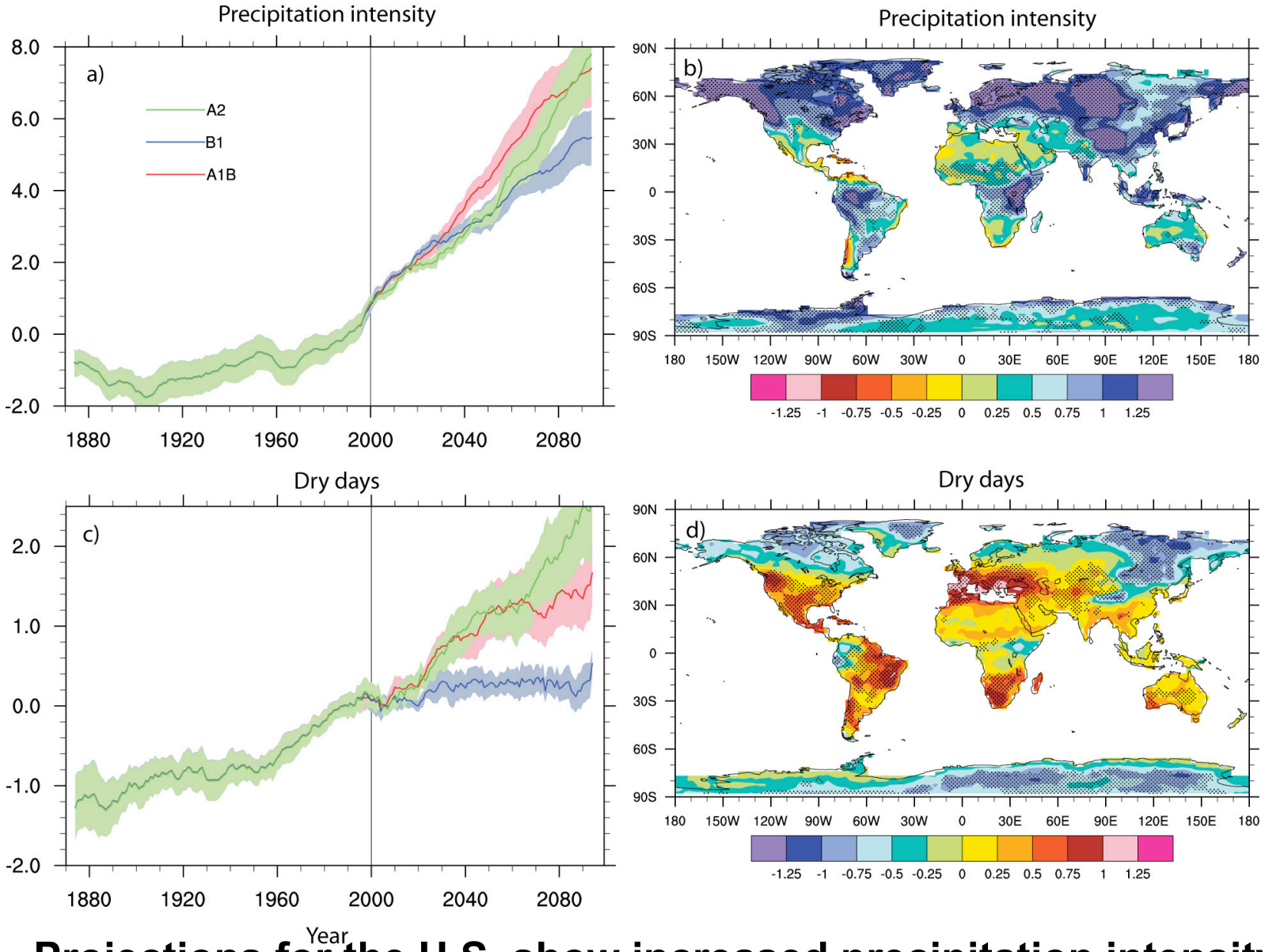
Not every day will be hot, just more of them

There will still be cold snaps, just less of them

So if you take an average over a year, it will be warmer than 20 years ago

Not every year will be warmer than the one before, but the overall trend over many years will be warmer



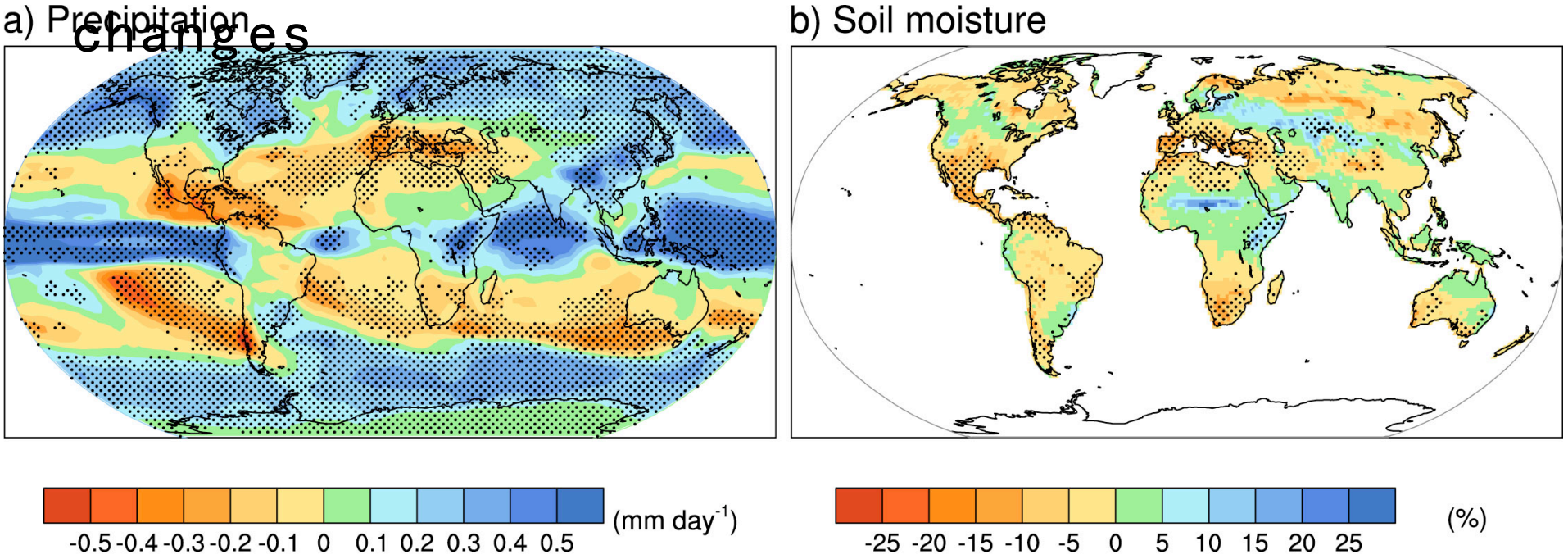


Projections for the U.S. show increased precipitation intensity but also increased dry days. Isn't that a contradiction of terms?

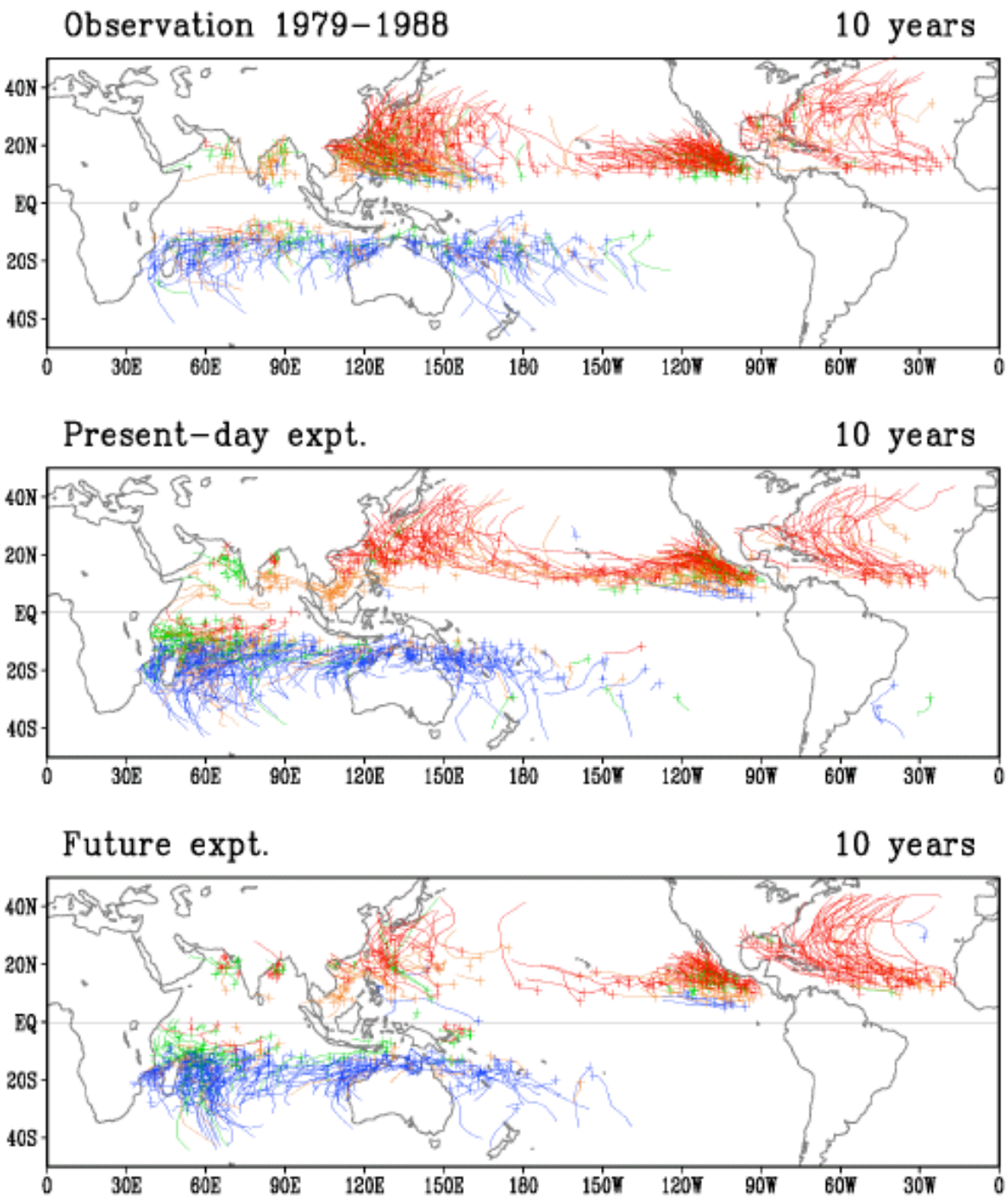
(Tebaldi , C., J.M. Arblaster, K. Hayhoe, and G.A. Meehl, 2006: Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. Clim. Change, **79,** doi 10.1007/s10584-006-9051-4.)

When it rains in a warmer climate, it rains a lot harder, but then there are longer gaps between rainfall events, so precipitation intensity increases *and* dry days increase

Combined effects of precipitation intensity and dry days contribute to mean precipitation changes



Are there any remaining mysteries? What about hurricanes, or the ice sheets and sea level rise? What about mitigation scenarios and the carbon cycle?

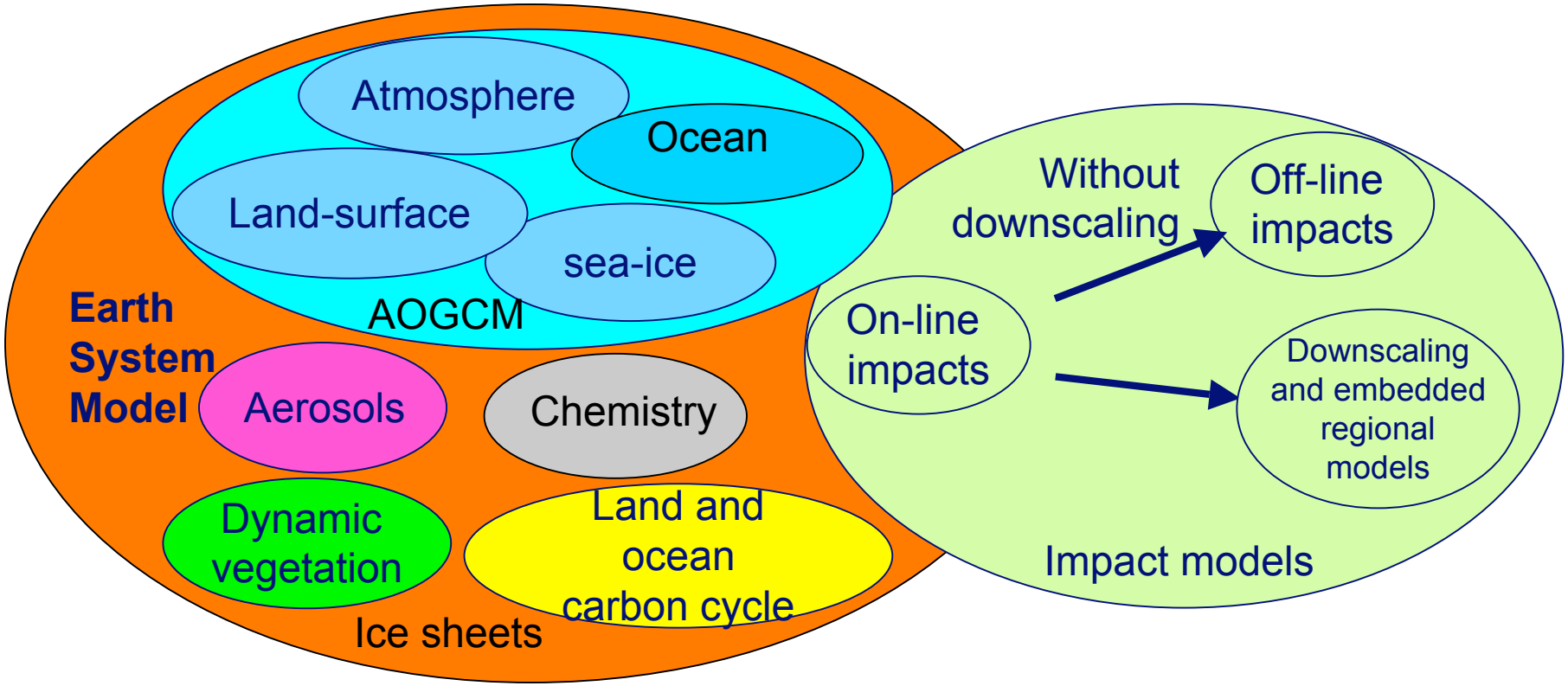


Tropical cyclone tracks from a global 20 km resolution AGCM

(Oouchi et al., 2006)

Will melting of the Greenland ice sheet be relatively slow, thus contributing to long term sea level rise on the order of centuries, or are there ice sheet instabilities that will enhance ice discharge into the ocean thus raising sea level more rapidly?

FROM ESMS TO IMPACTS



Schematic of an AOGCM (oval at upper left) and Earth System model (in orange oval) and various types of impact models (right).

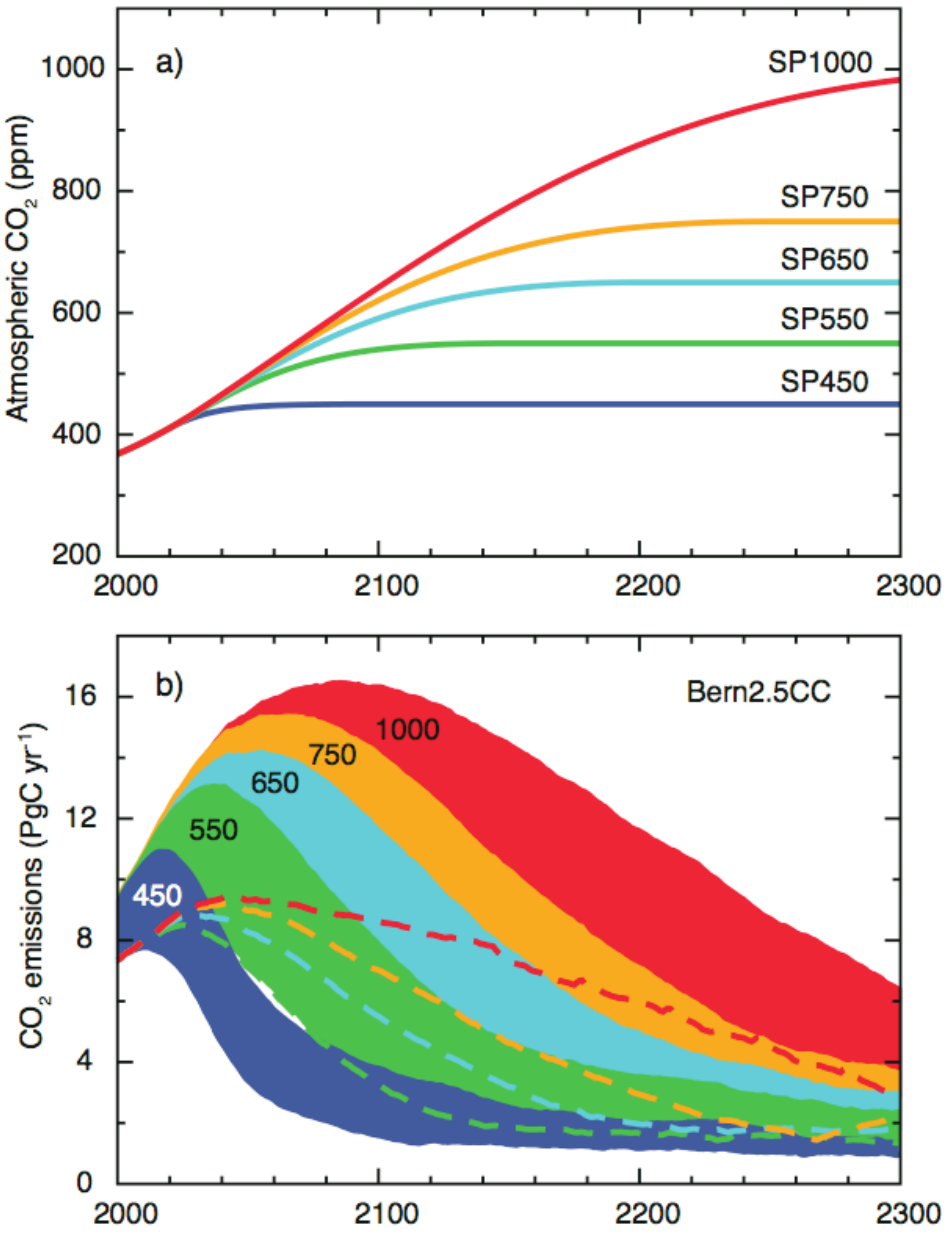
A new mystery:
Mitigation/adaptation

New mitigation scenarios run with earth system models will have implicit policy actions to target future levels of climate change

But we can only mitigate part of the problem, and we will have to adapt to the remaining climate change

The mystery: what are the time-evolving regional climate changes that human societies will have to adapt to?

(use new generation of climate models to help solve this mystery)



Summary

1. Climate models have helped us solve one of the great mysteries of climate science, the time evolution of 20th century temperatures, by allowing us to deconstruct the various factors, natural and anthropogenic, that influenced the temperature record, thus building confidence that these models can provide potentially useful information about future climate
2. A large coordinated set of climate model experiments run by the modeling groups around the world allowed us to address future climate mysteries involving climate change commitment, extremes, and probabilistic future climate change
3. A number of mysteries remain. There is still uncertainty regarding hurricanes and the pace of ice sheet melt and contribution to sea level rise in the 21st century, and new ice sheet models are being formulated. Short term (next 2-3 decades) climate change, mitigation scenarios, and carbon cycle feedback will be addressed in a new set of coordinated experiments currently being planned.
4. A key mystery: If human society can mitigate climate change to a certain level, then what is the regional time-evolving nature of climate change to which we must then adapt?