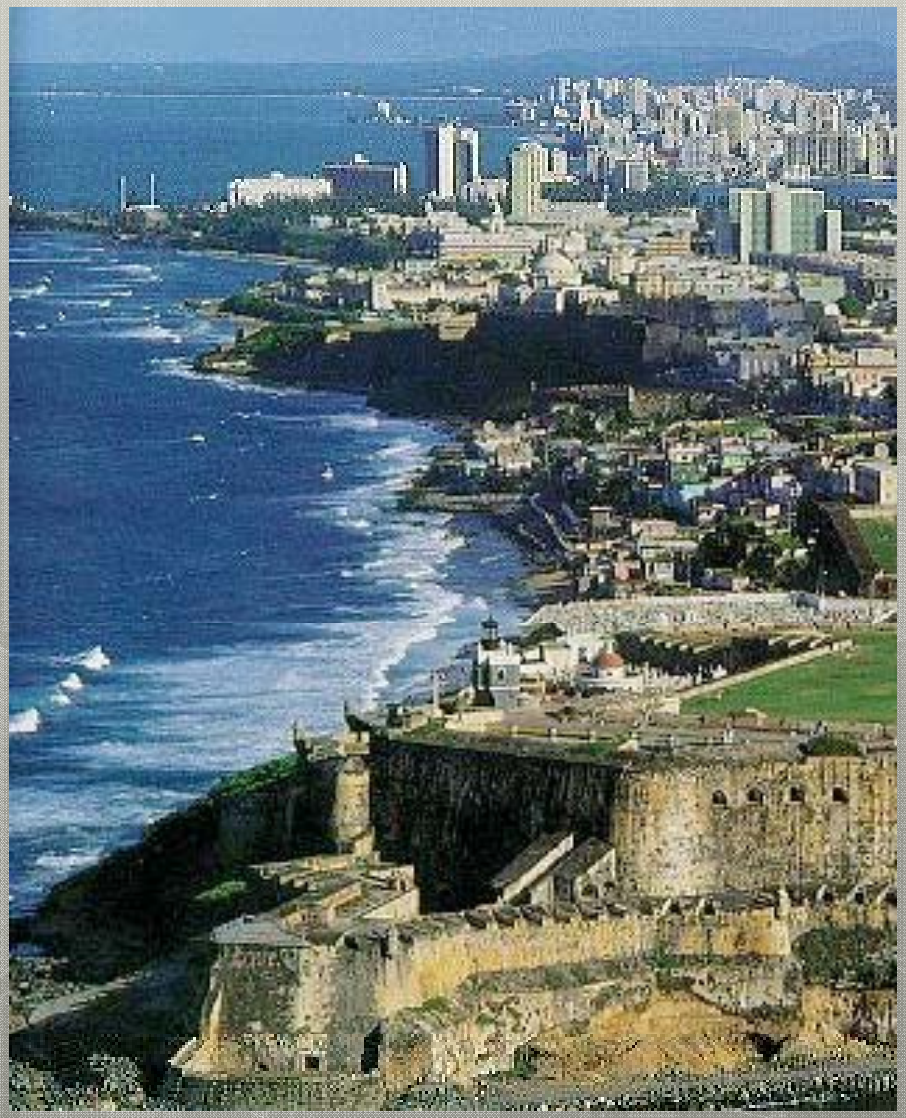
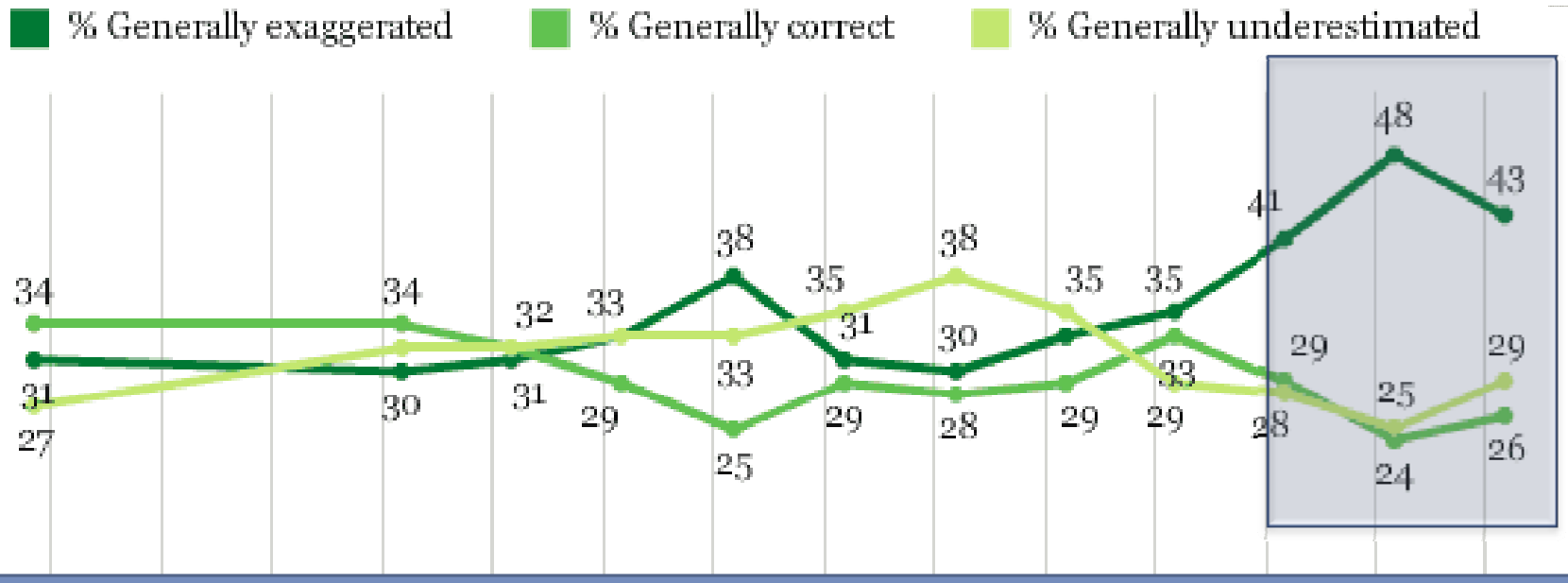


What is global climate change and why does it matter for the U.S. Caribbean?

KATHARINE HAYHOE
TEXAS TECH UNIVERSITY

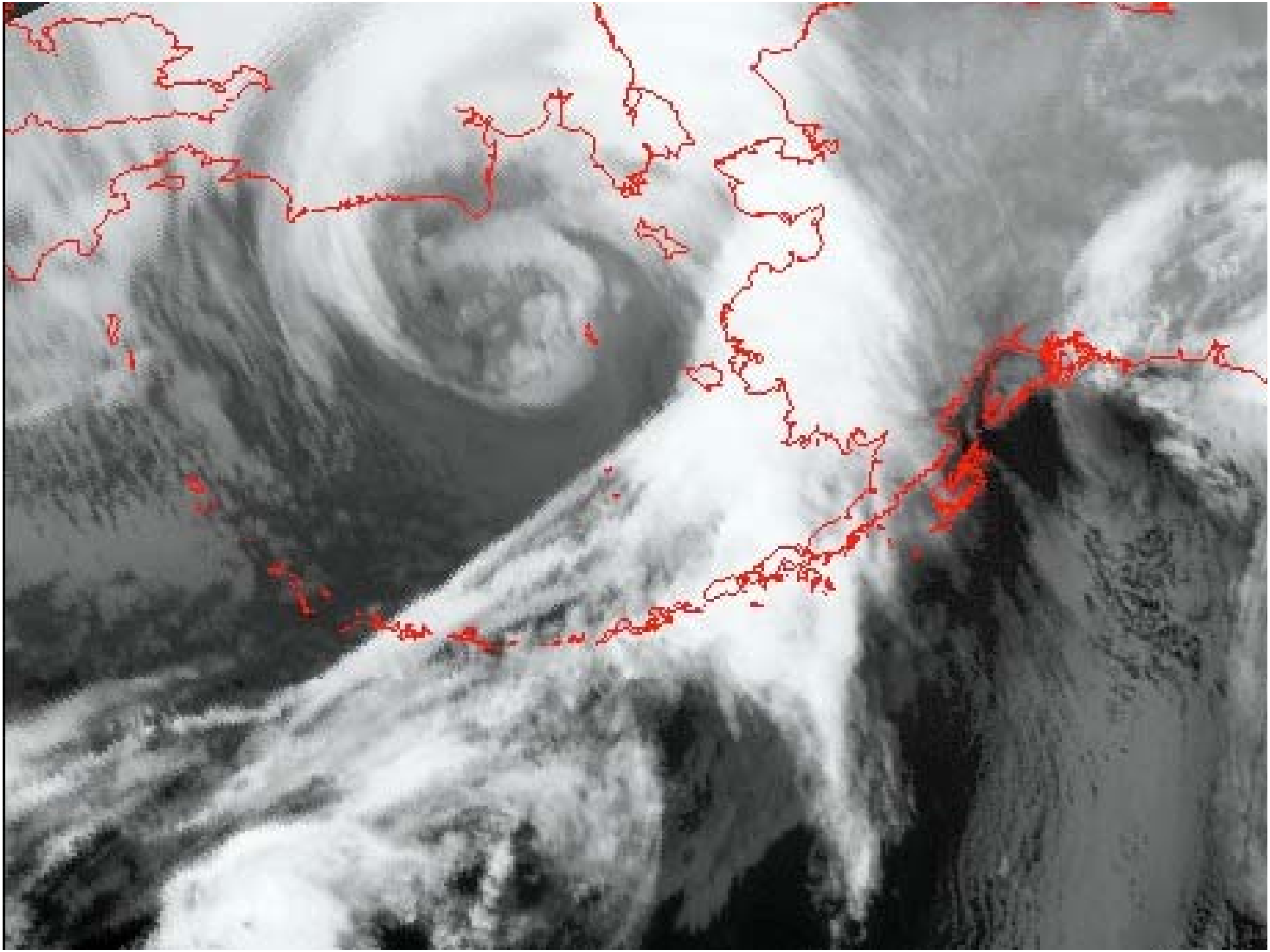
Doubt on seriousness of global warming at all-time high

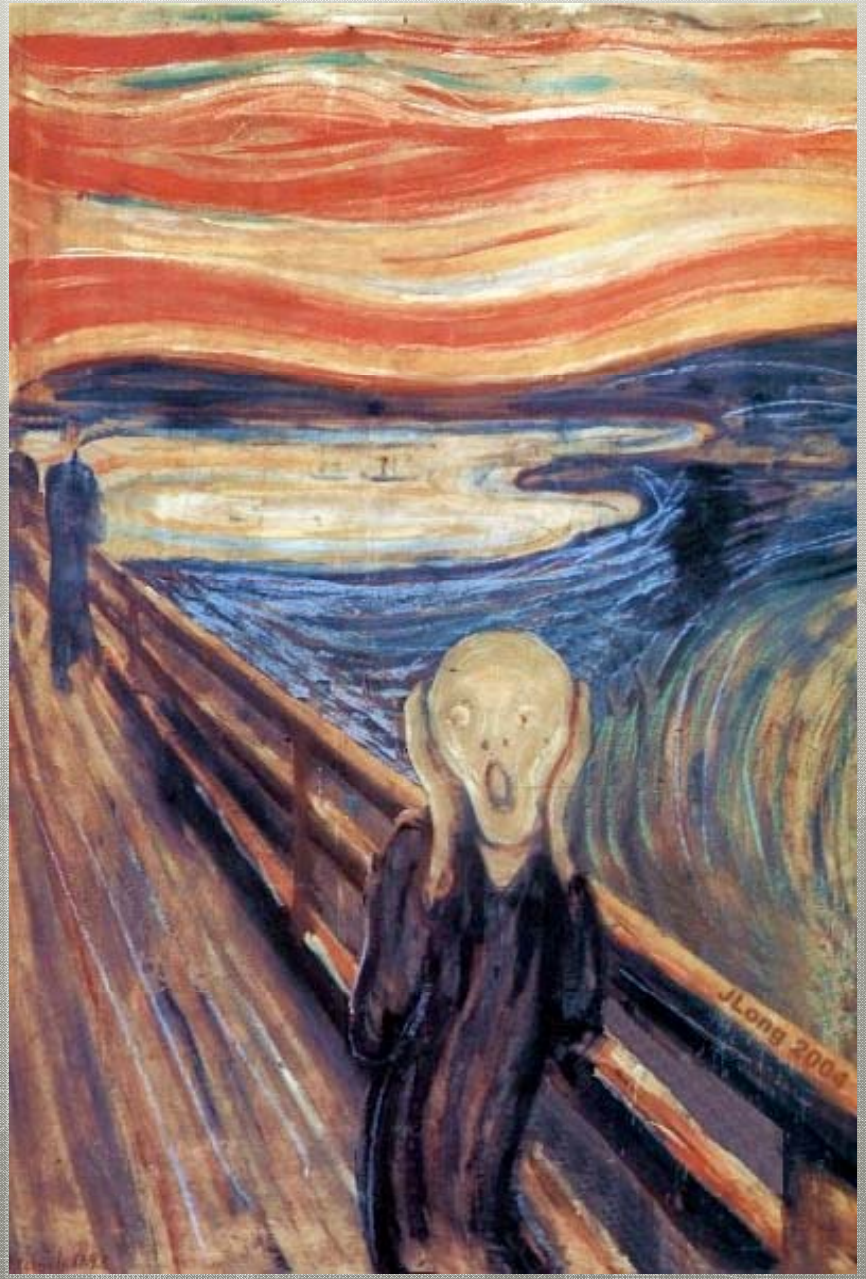
Thinking about what is said in the news, in your view is the seriousness of global warming -- [ROTATED: generally exaggerated, generally correct, or is it generally underestimated]?



...but are there any facts?

The facts of life in Kivalina, Alaska

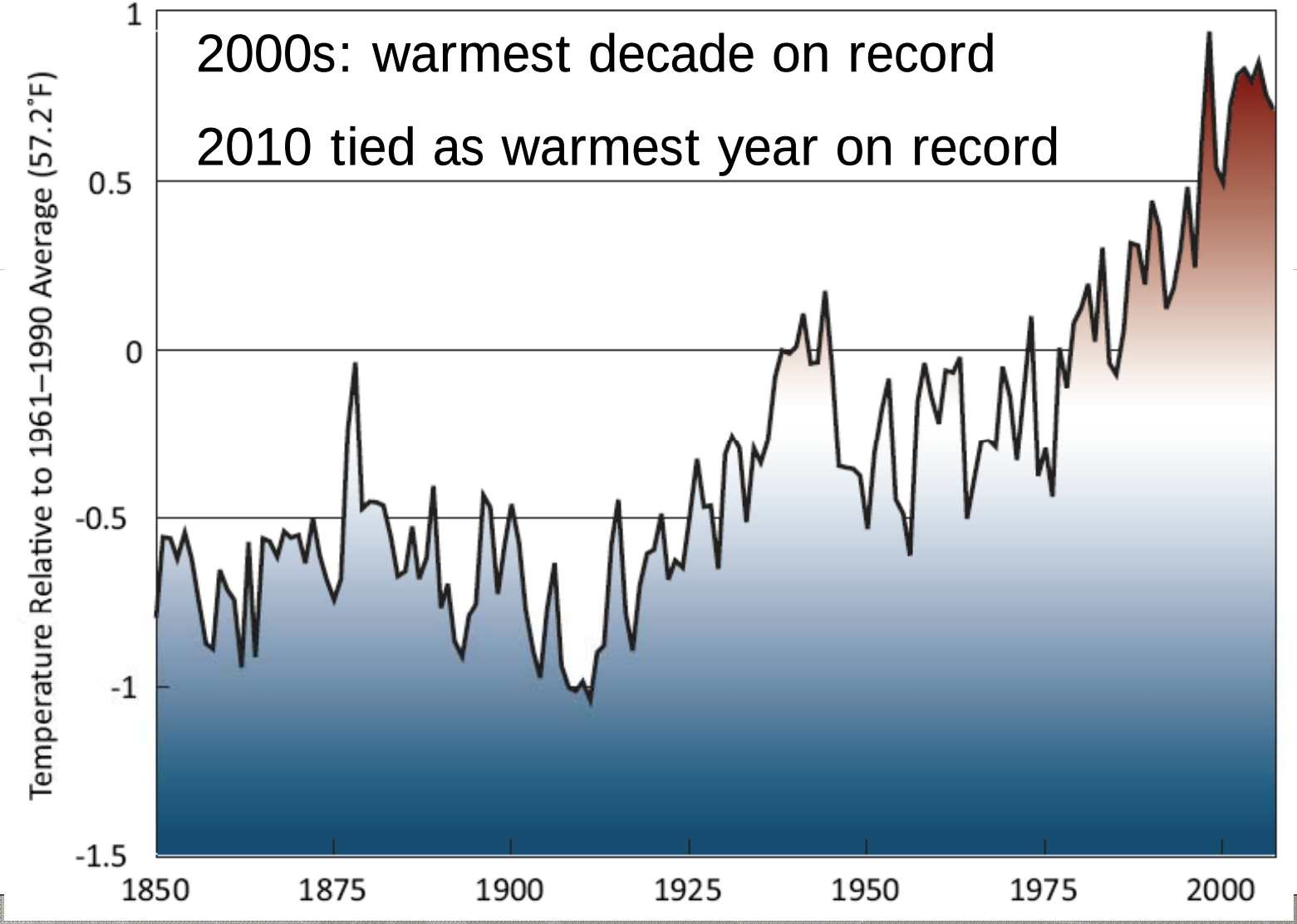




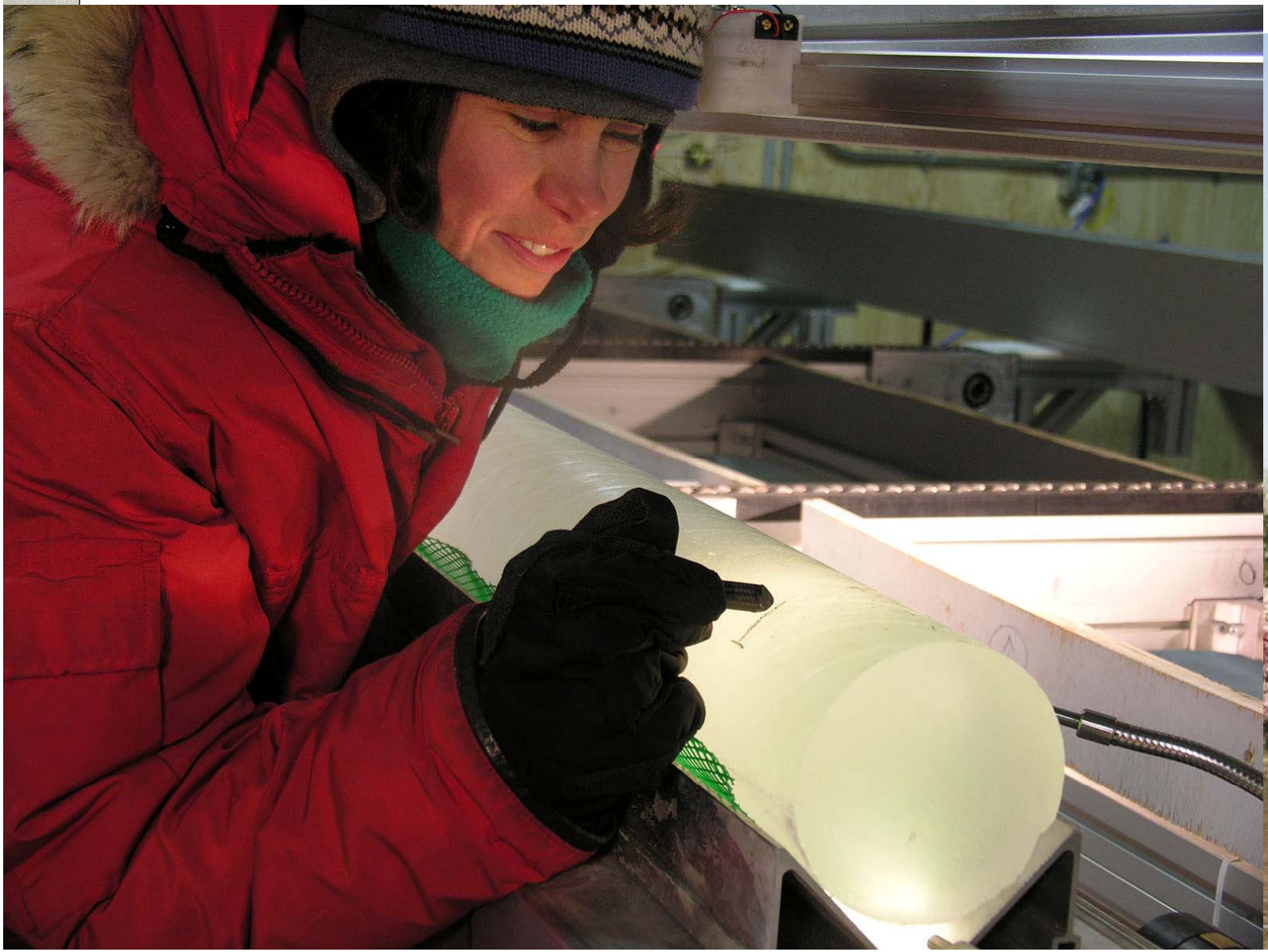
WHAT IS HAPPENING TO OUR WORLD?

PART ONE

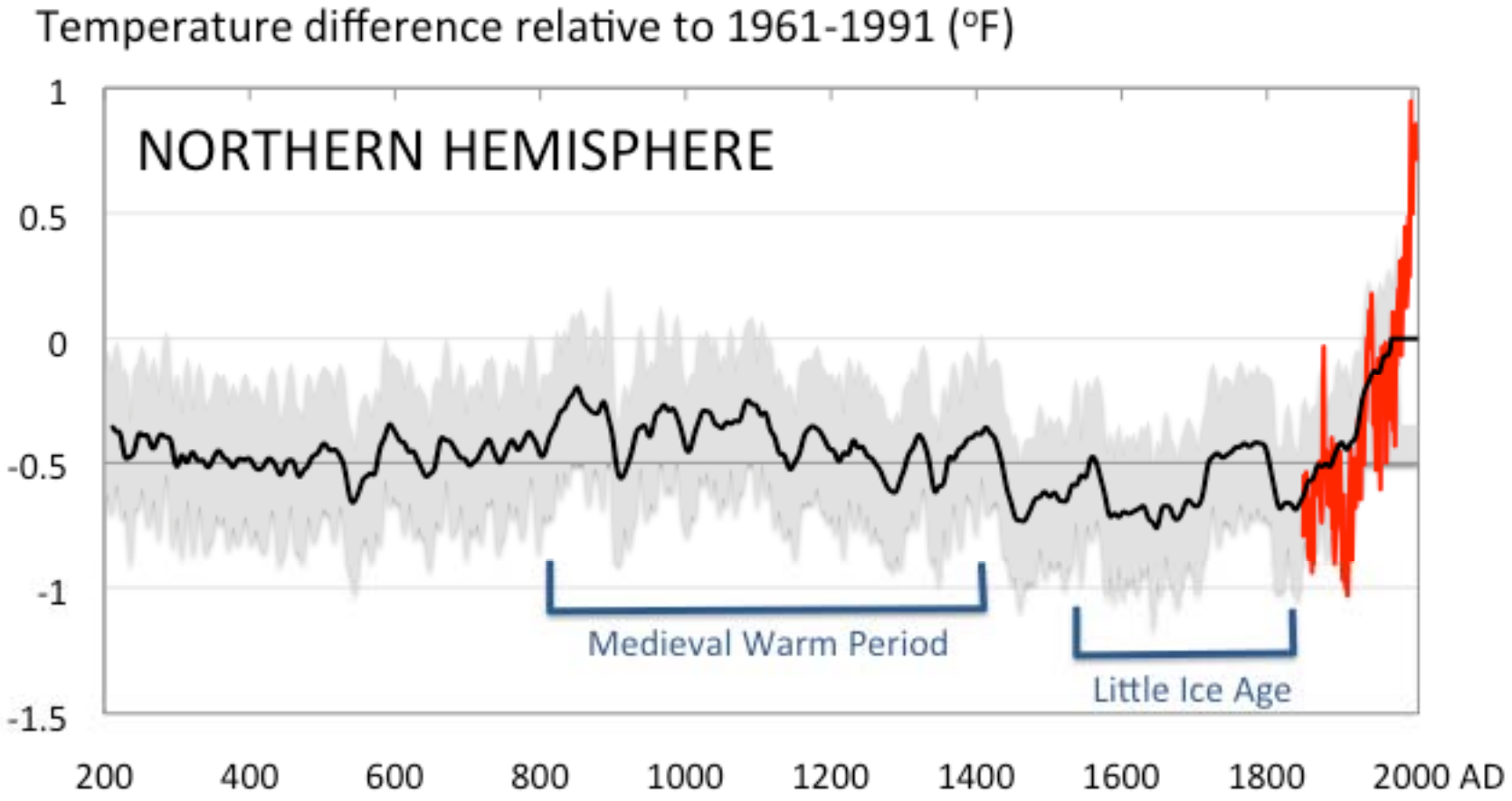
The Earth is getting warmer



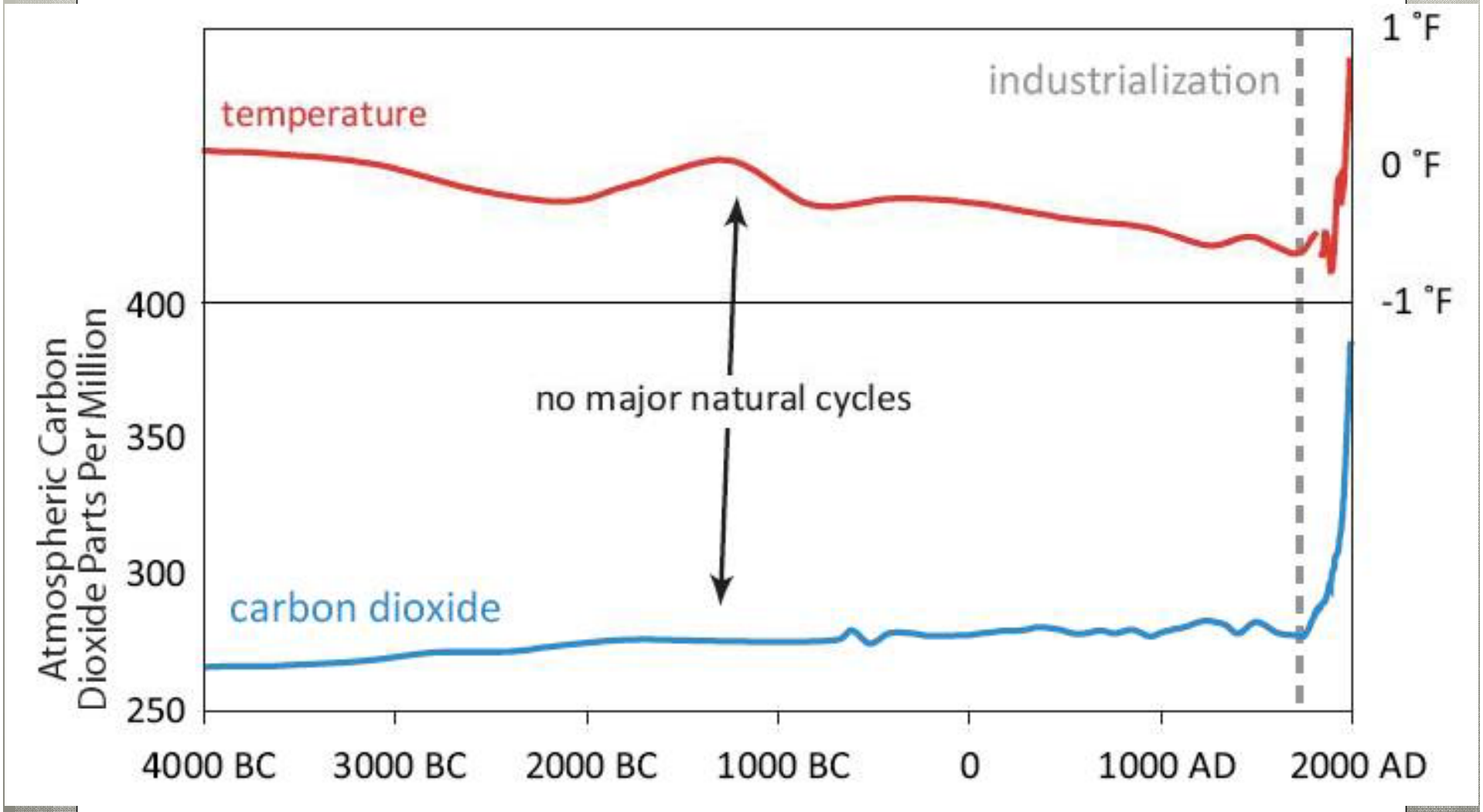
“Natural” thermometers tell us...



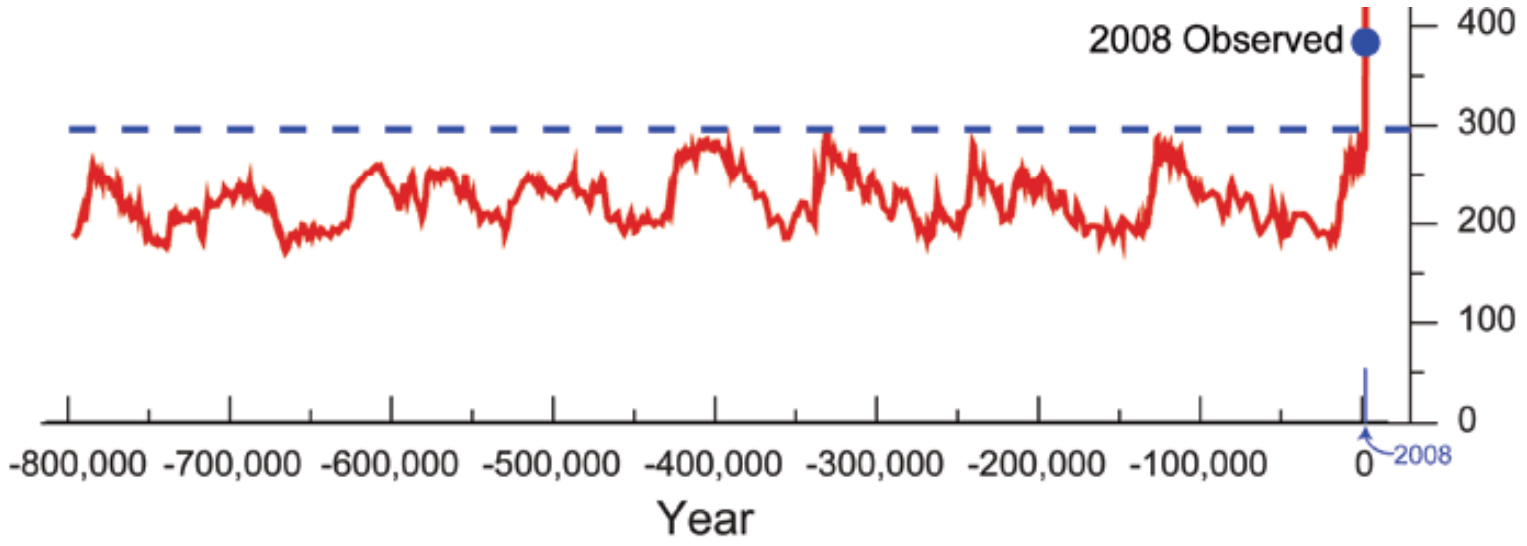
Conditions today are unusual in the context of the last 2,000 years …



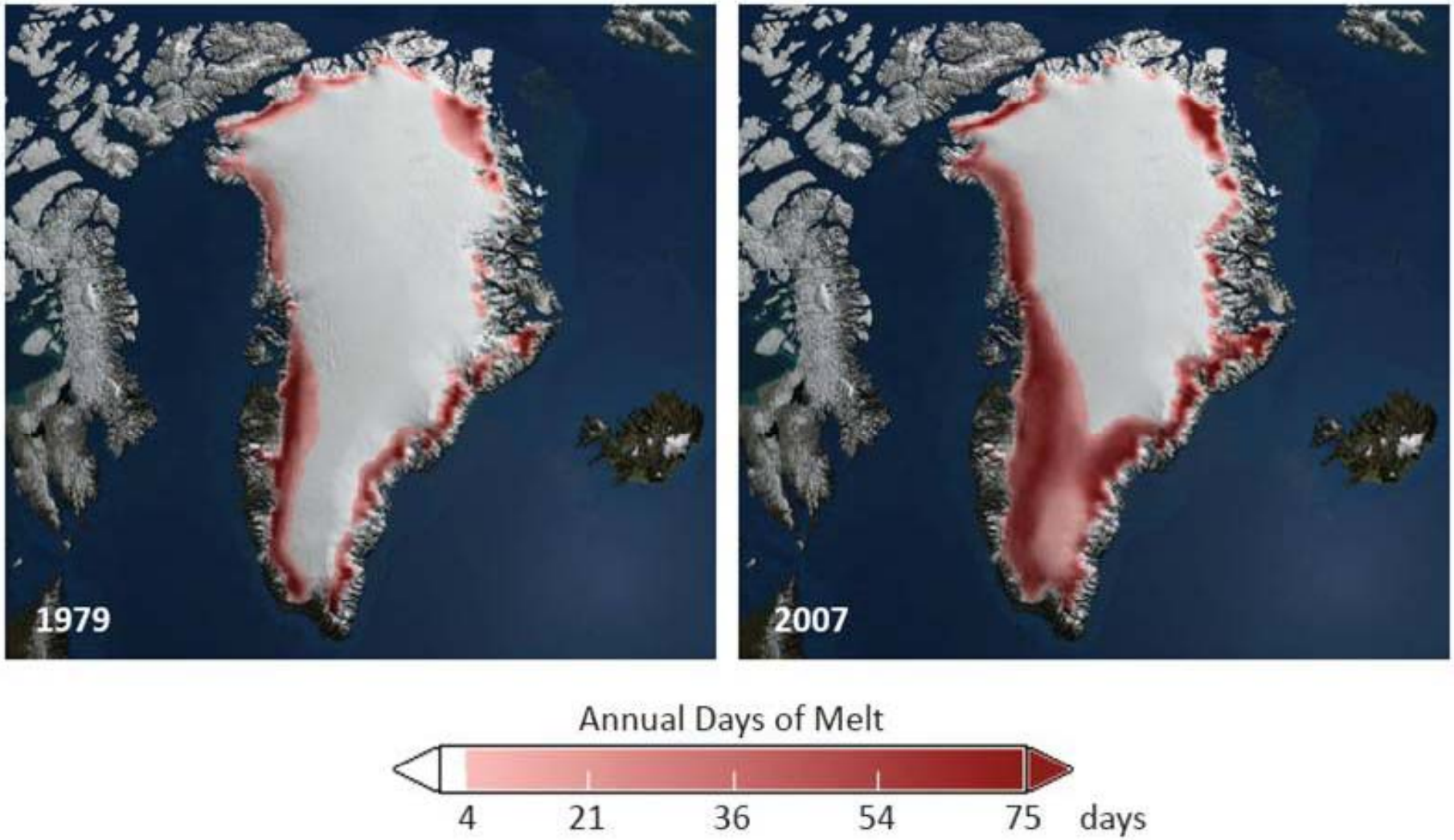
… the last 6,000 years



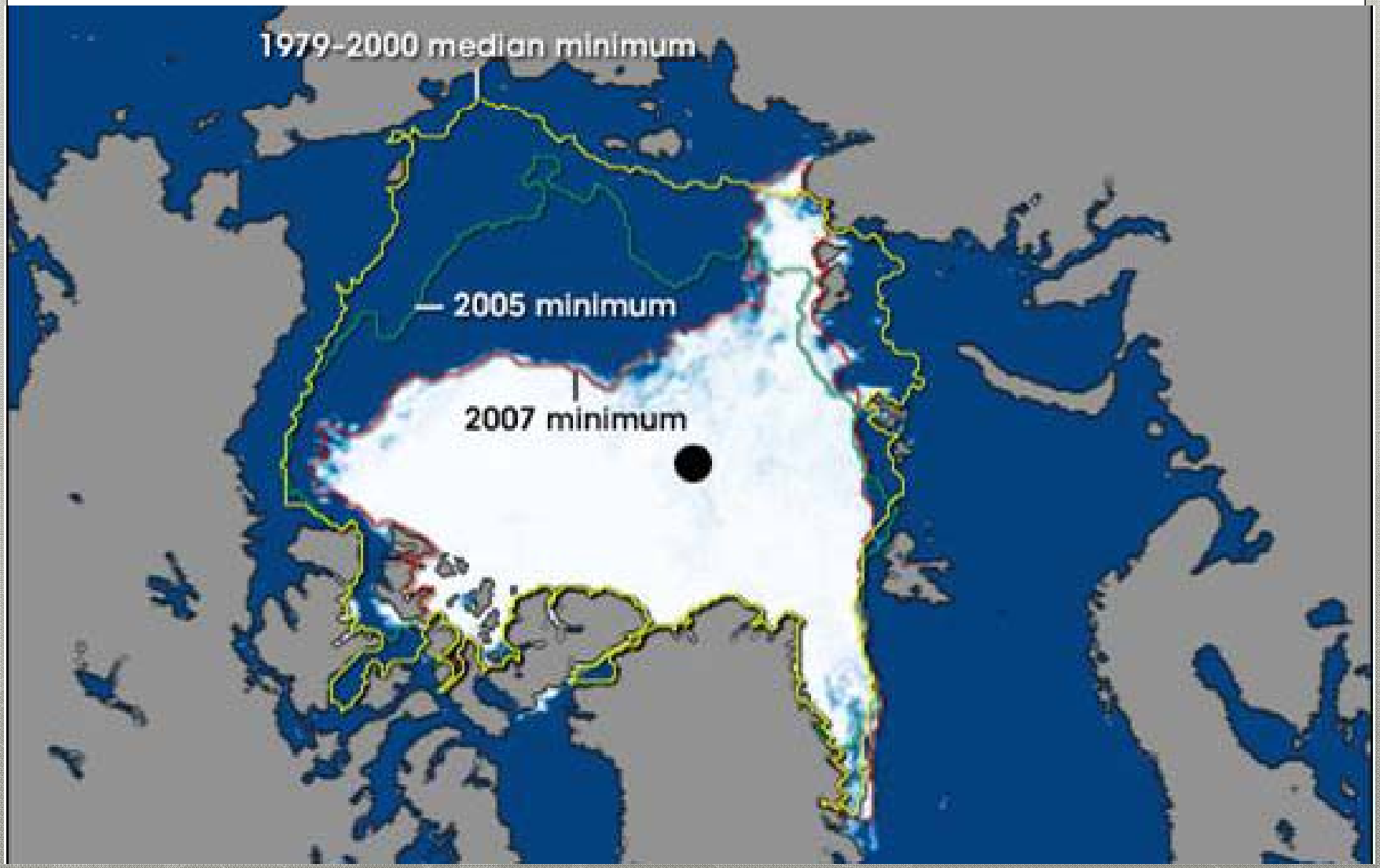
… and even the last 800,000 years



Sea level is rising, as ice sheets melt



Arctic is changing, as sea ice shrinks



Too much water, as glaciers melt

Blomstrandbrennen Glacier in Norway

Too much water, as glaciers melt

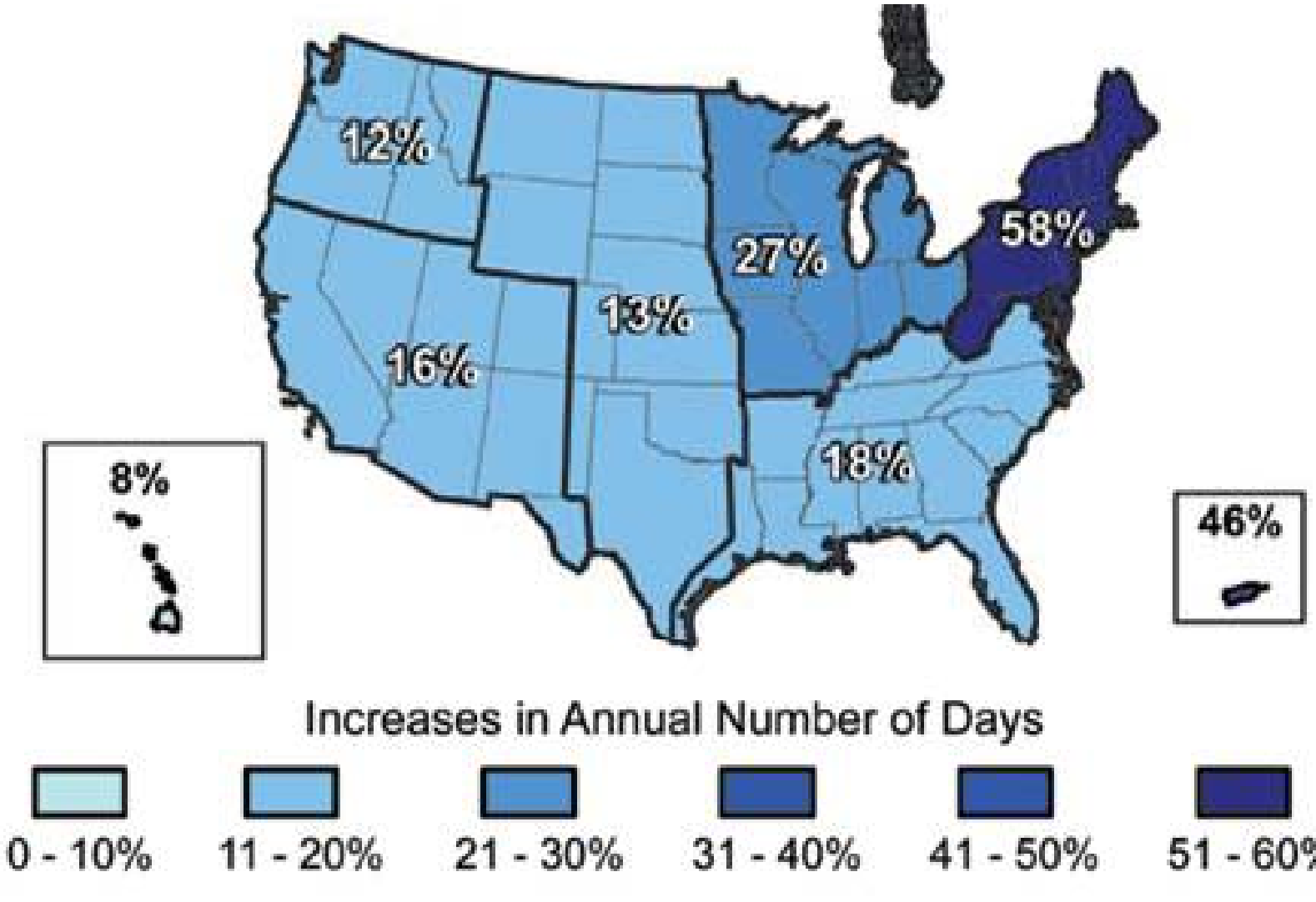
Franz Josef Glacier, New Zealand

Not enough, when they do …

LIMA, PERU
8 million people
less than 2” rain per yr

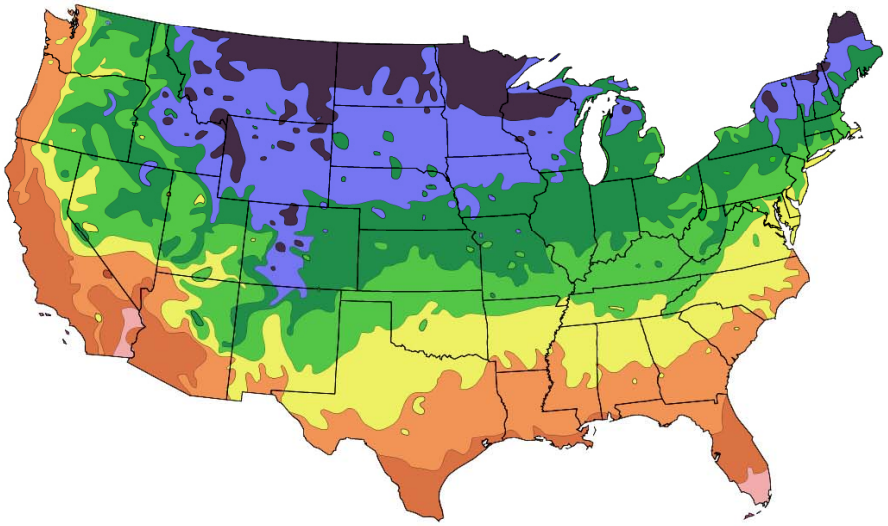
1 billion world-wide
depend on glacier
melt for water

Extreme rainfall becoming more frequent



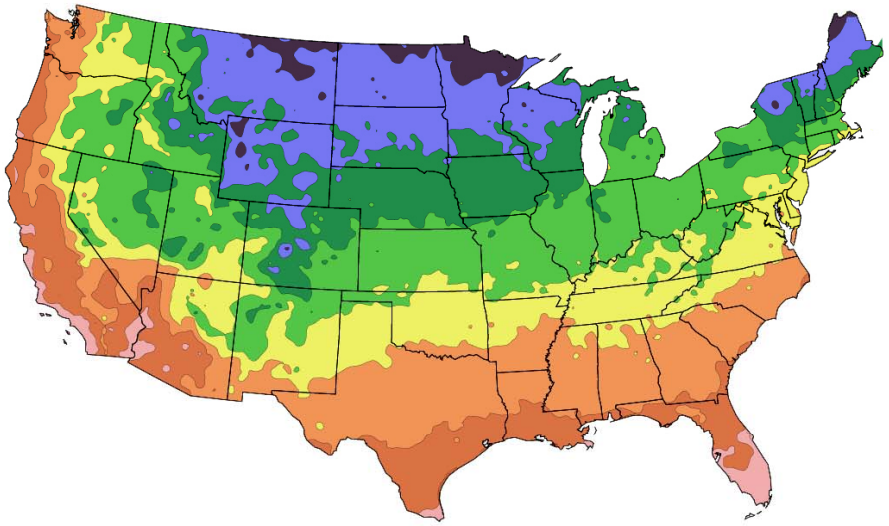
Ecosystems shifting, as temperatures warm

1990 Map



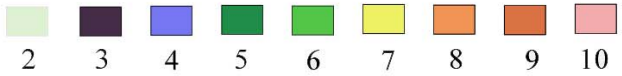
After USDA Plant Hardiness Zone Map, USDA Miscellaneous Publication No. 1475, Issued Januay 1990

2006 Map



National Arbor Day Foundation Plant Hardiness Zone Map published in 2006.

Zone



Where we live today feels like it used to ~200 miles south, just 25 years ago.

Our world is changing rapidly

Responses to warming temperatures seen in more than 26,500 physical and biological systems around the world.

Rosenzweig et al. 2008

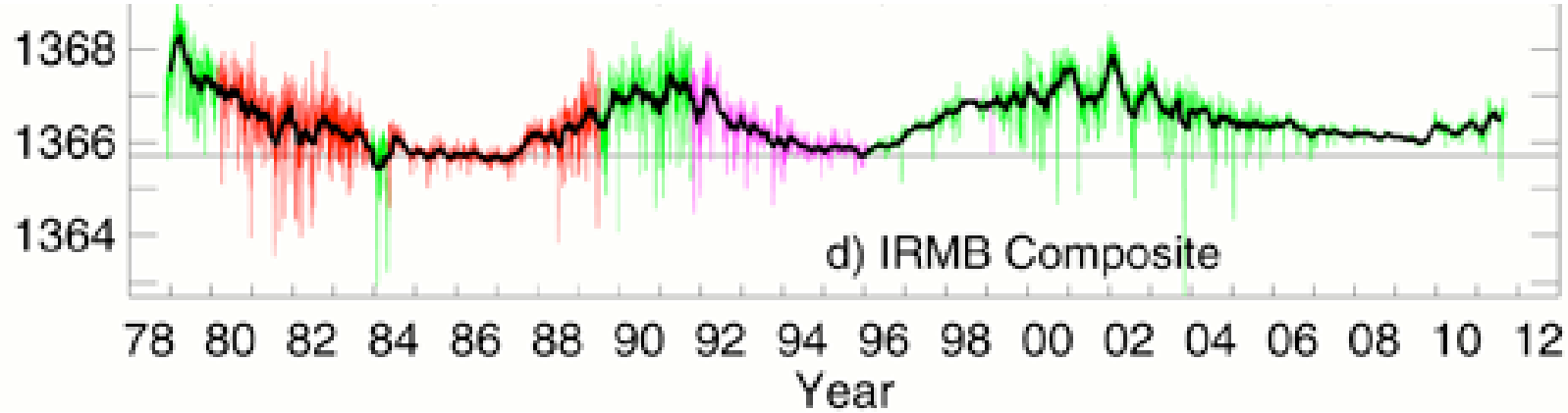
WHY IS THIS HAPPENING?

PART TWO

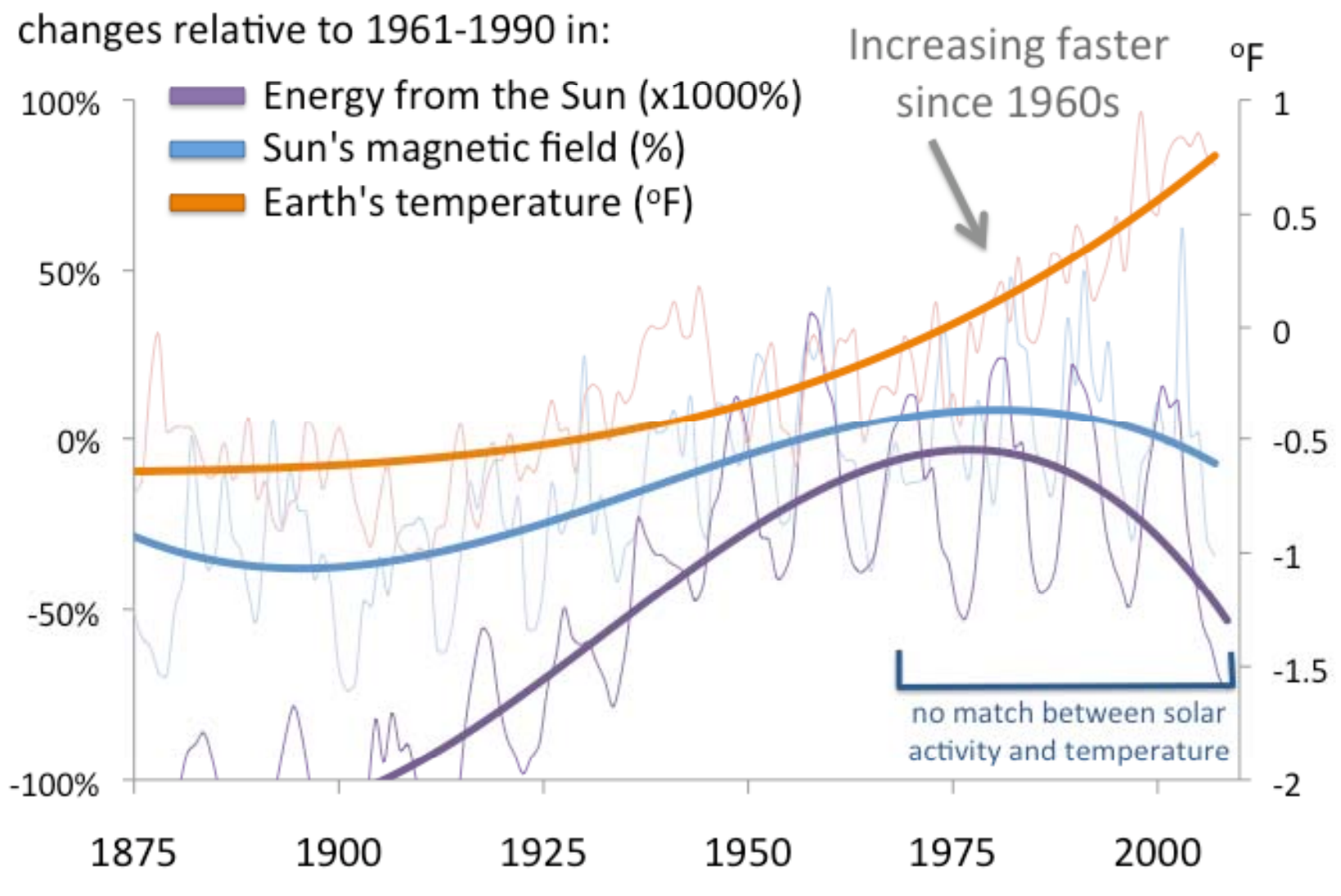
The Usual Suspects

NATURAL VARIABILITY

Changes in energy from the sun that reduce or increase the energy received by the earth over years to millennia



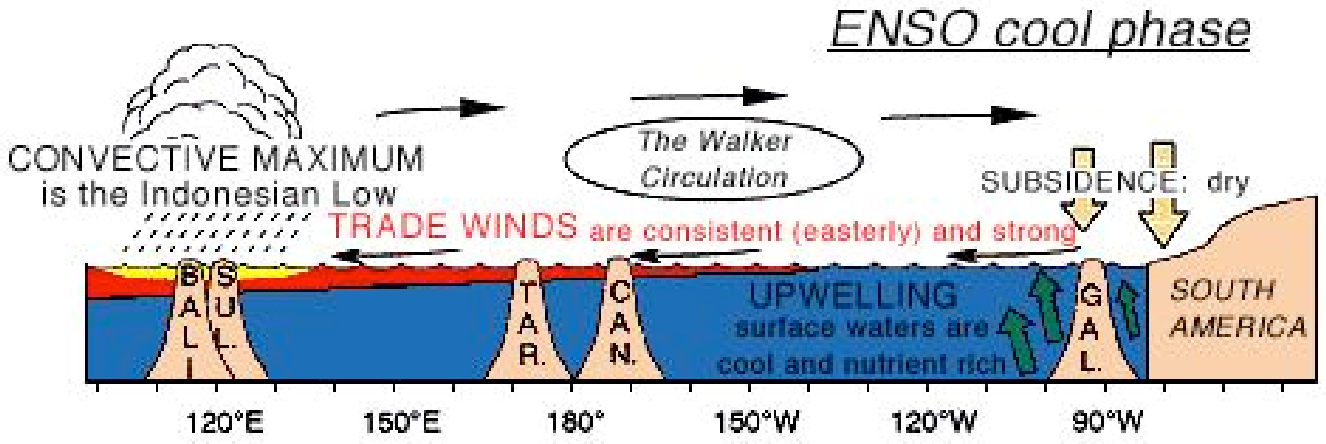
But the sun has a perfect alibi



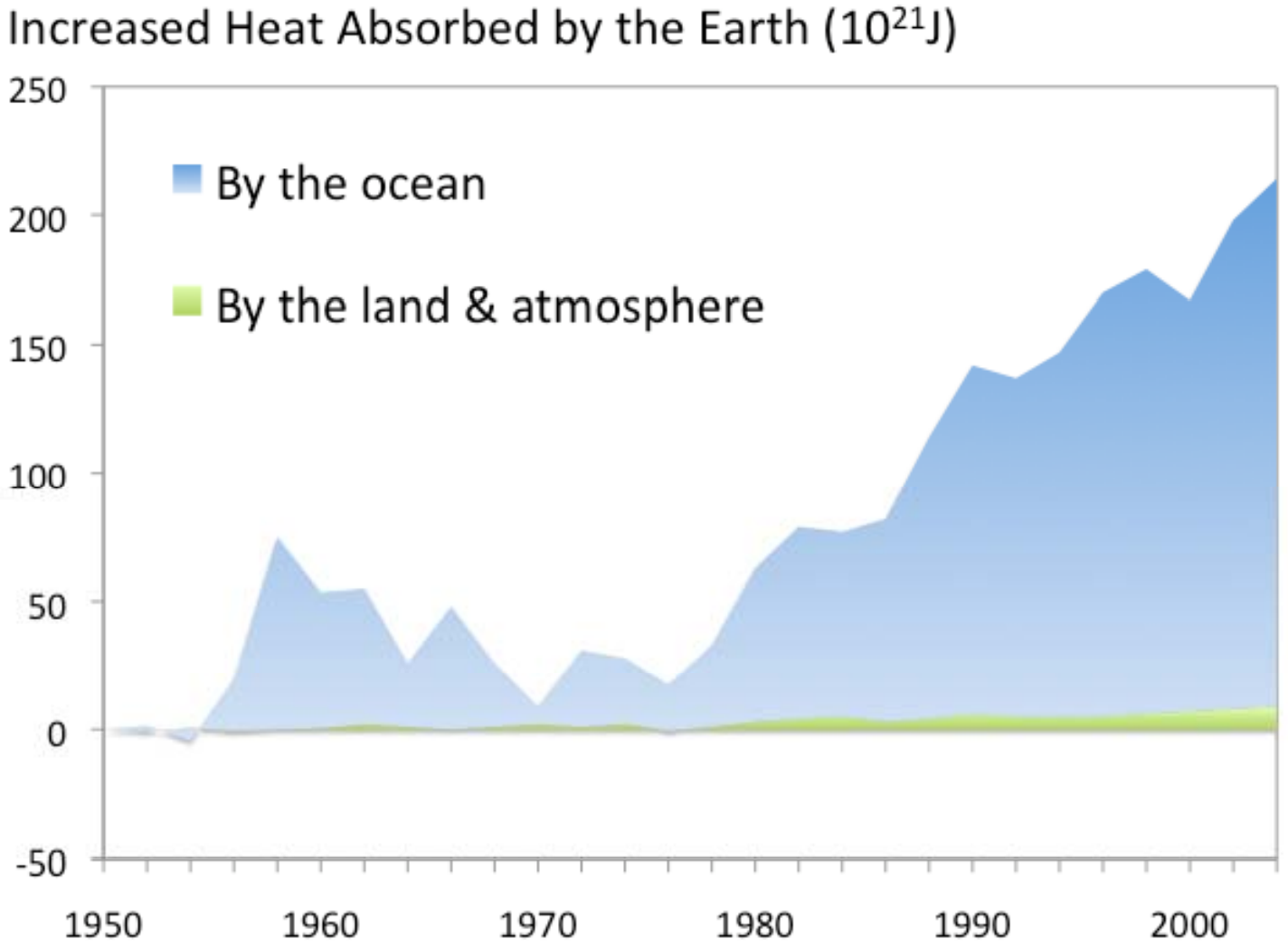
The Usual Suspects

NATURAL VARIABILITY

Internal cycles that exchange heat between the ocean and atmosphere, altering weather patterns around the world on timescales from 30 days up to 120 years or more



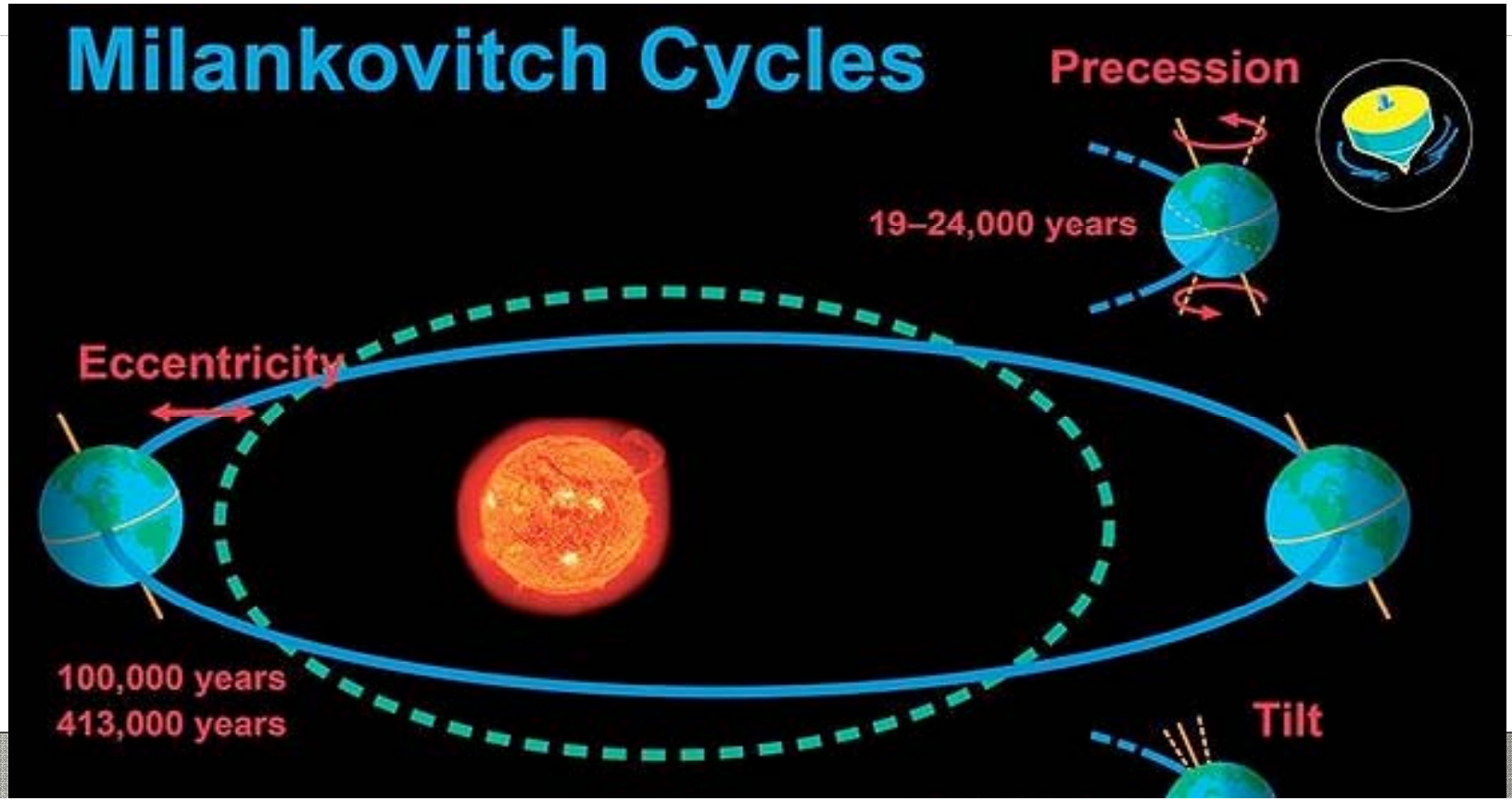
Ocean AND atmosphere are warming



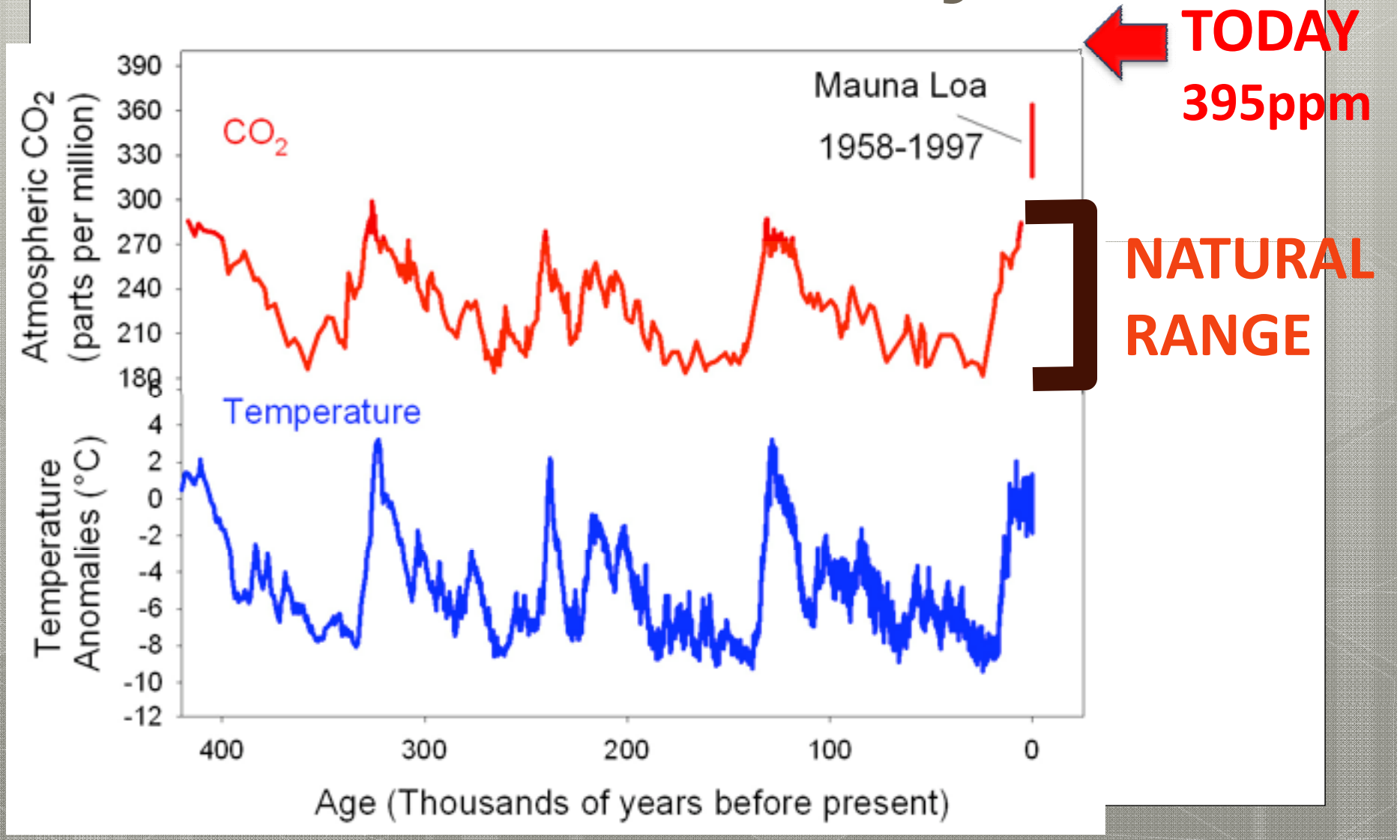
The Usual Suspects

NATURAL VARIABILITY

Orbital cycles that alter amount of energy received

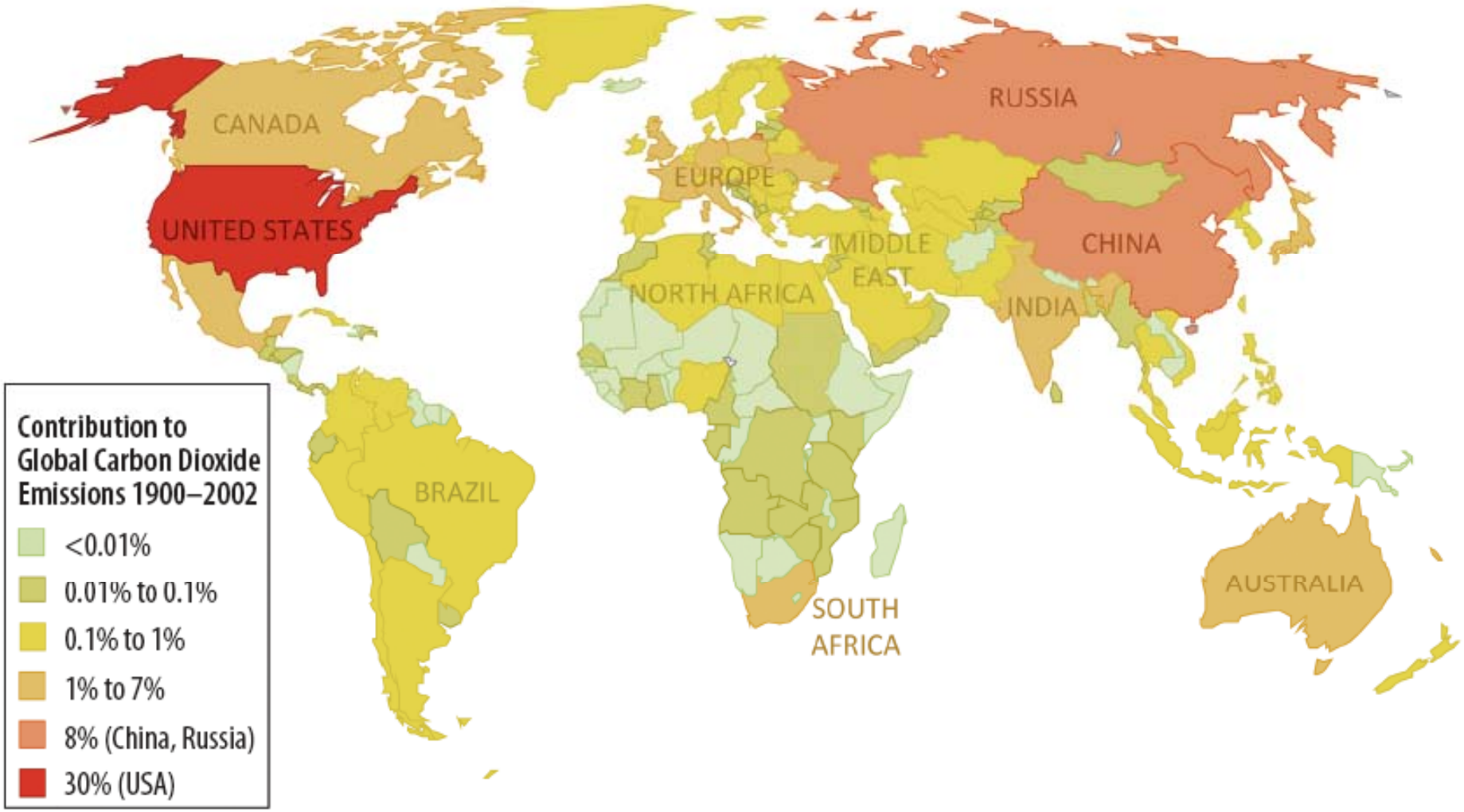


Can't blame orbital cycles

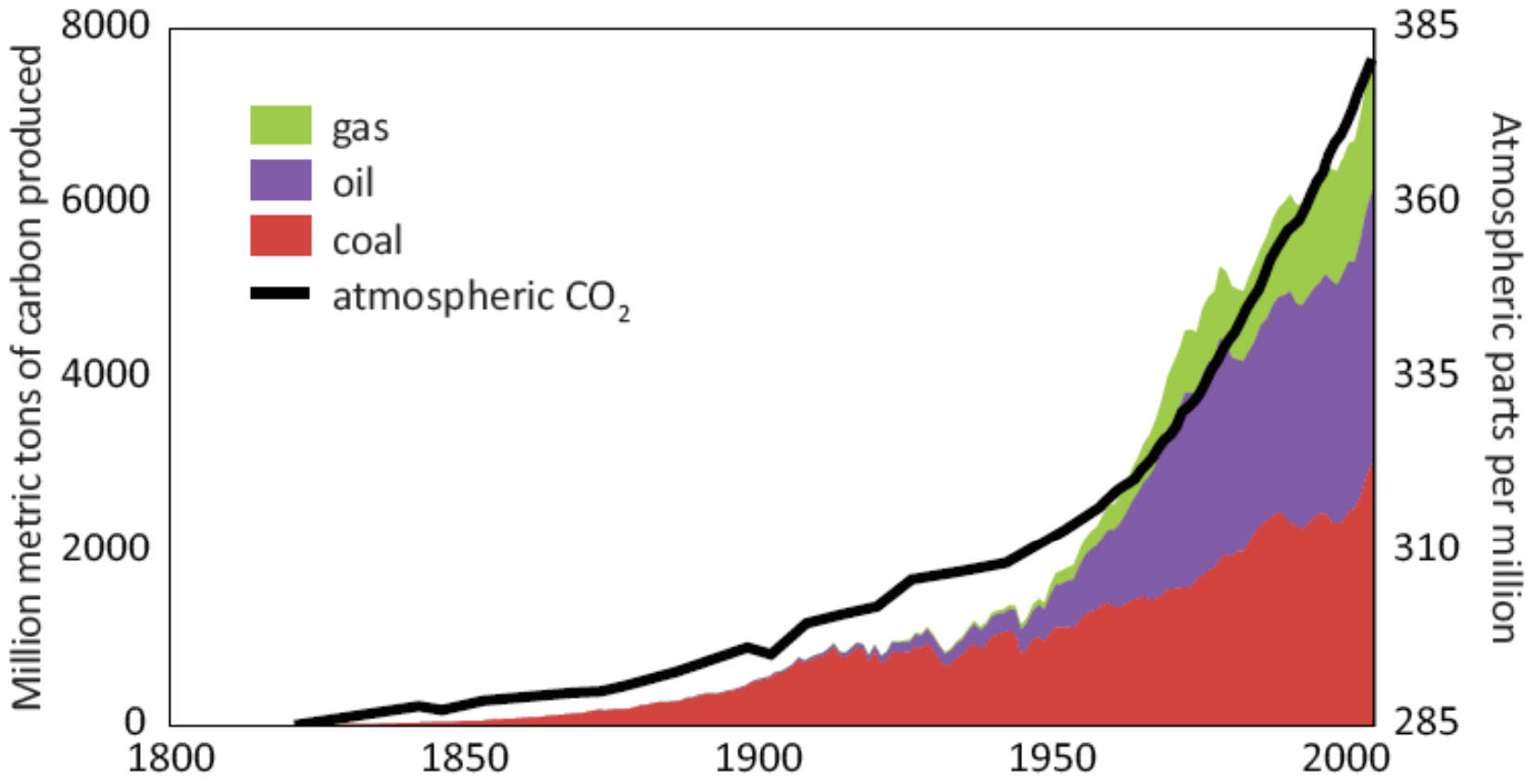


Our activities produce heat-trapping gases

The U.S. is one of the biggest producers



These gases are building up in the atmosphere



Why are these gases a problem?

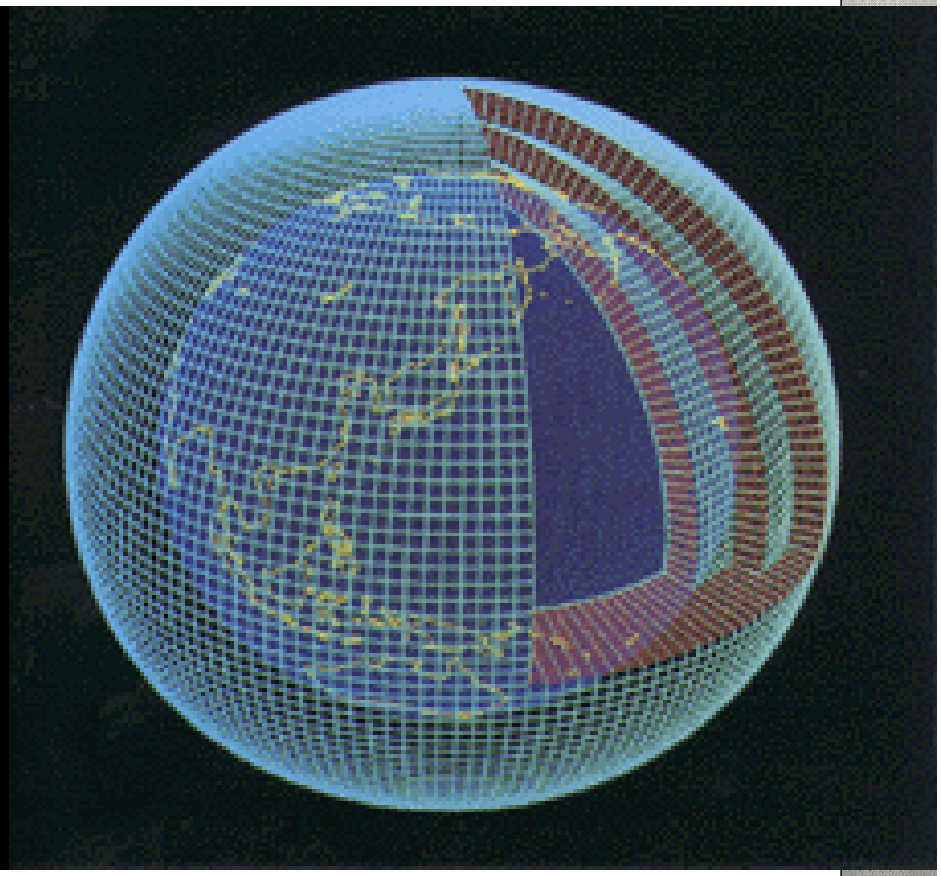
THE NATURAL GREENHOUSE EFFECT

naturally increases Earth's temperature by ~60°F

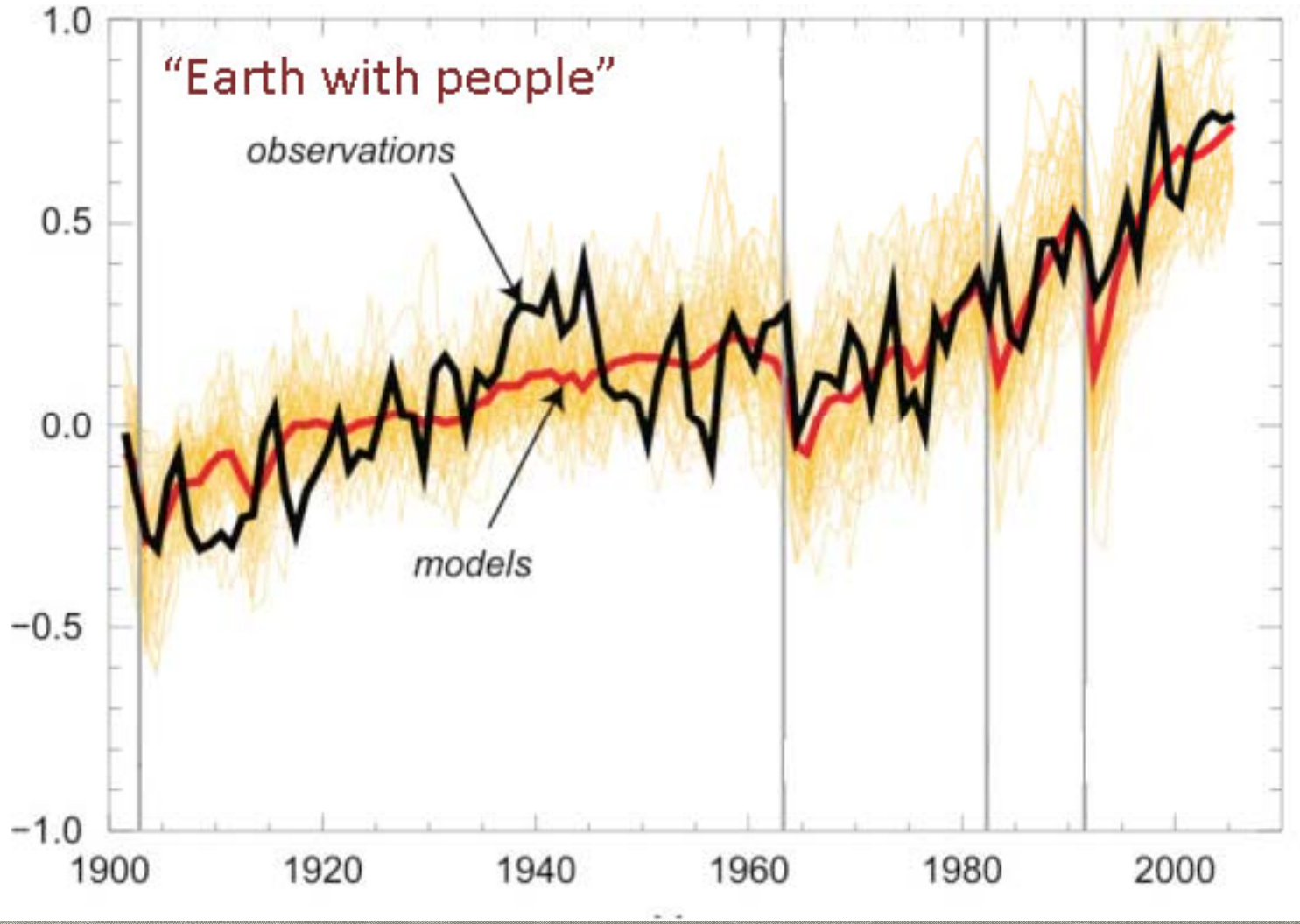
THE ENHANCED GREENHOUSE EFFECT

has artificially increased Earth's temperature by 1.4°F

How do we know this is happening?



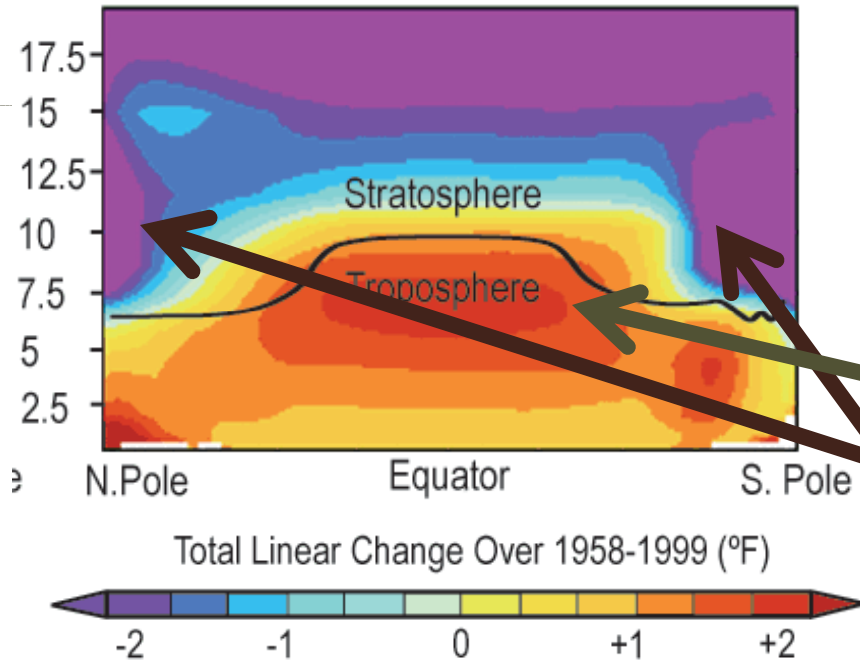
Quantifying the human influence

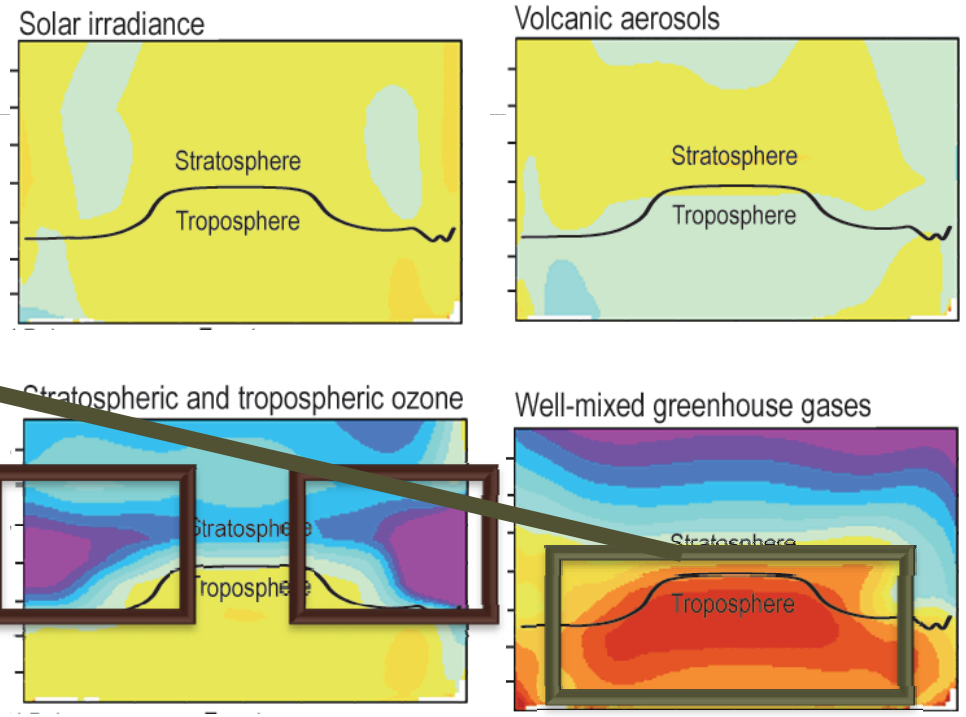


“Fingerprinting” for global change

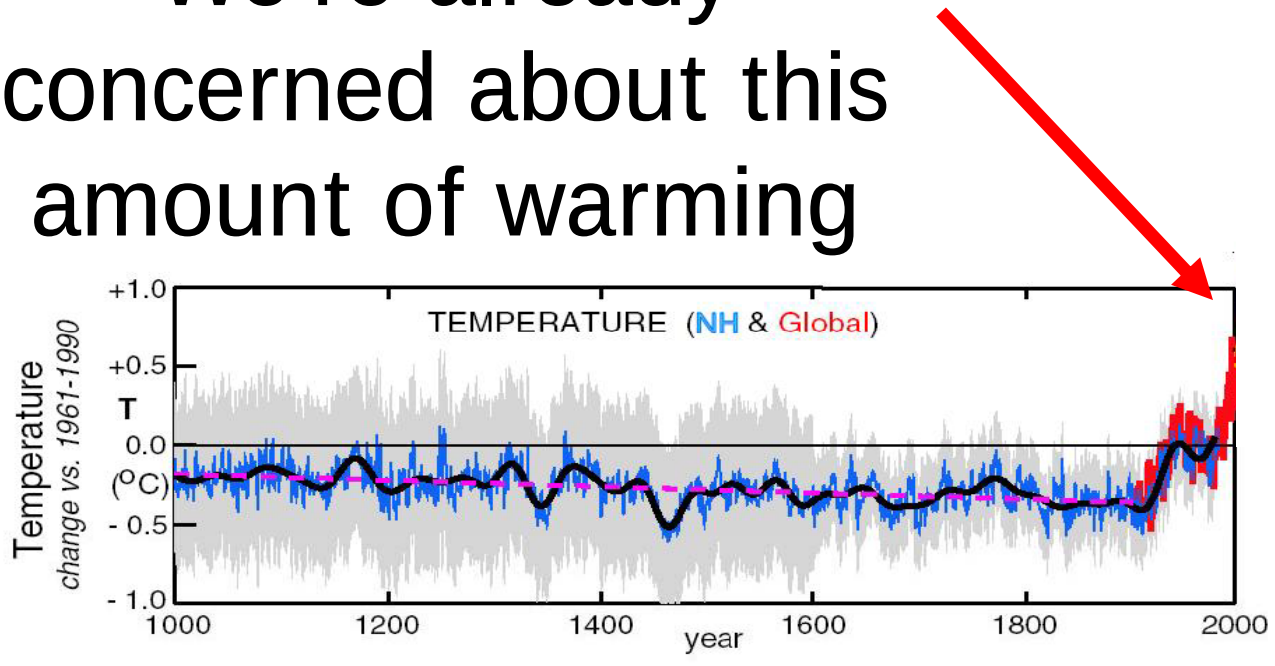
OBSERVED CHANGES IN ATMOSPHERIC TEMPERATURE

SIGNATURES OF POSSIBLE CULPRITS



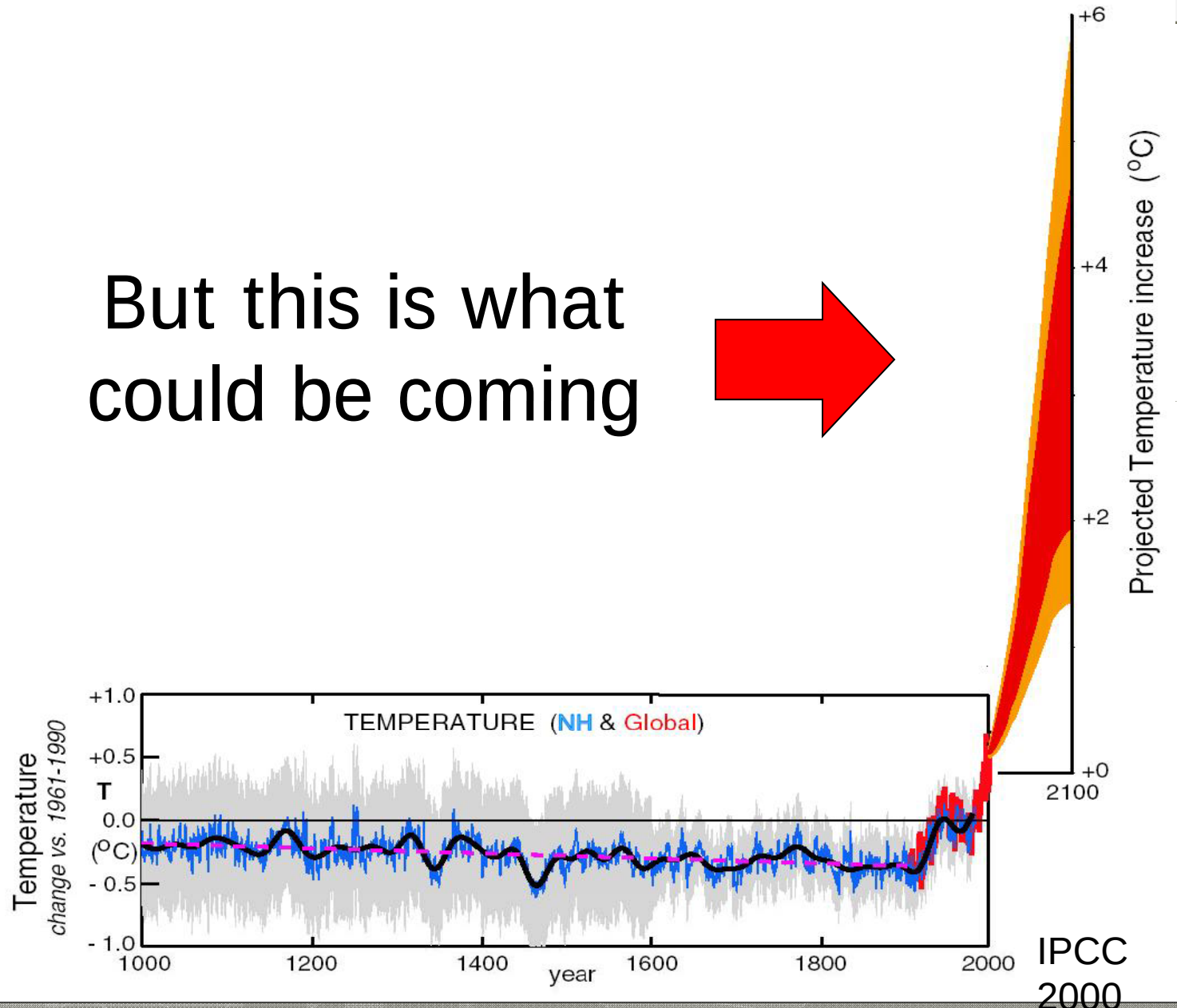


We're already concerned about this amount of warming



IPCC 2000

But this is what could be coming



IPCC 2000

PREDICTING THE FUTURE

PART THREE

~~PREDICTING~~

PROJECTING THE FUTURE

PART THREE

Why are future projections uncertain?

1. On-going natural variations in climate are chaotic, making it difficult to predict conditions over timescales shorter than a decade
2. We don't know exactly how sensitive the climate system is to these emissions
3. Our ability to simulate the climate system is limited and incomplete, particularly at the local/regional scale
4. We don't know what future emissions from human activities will be

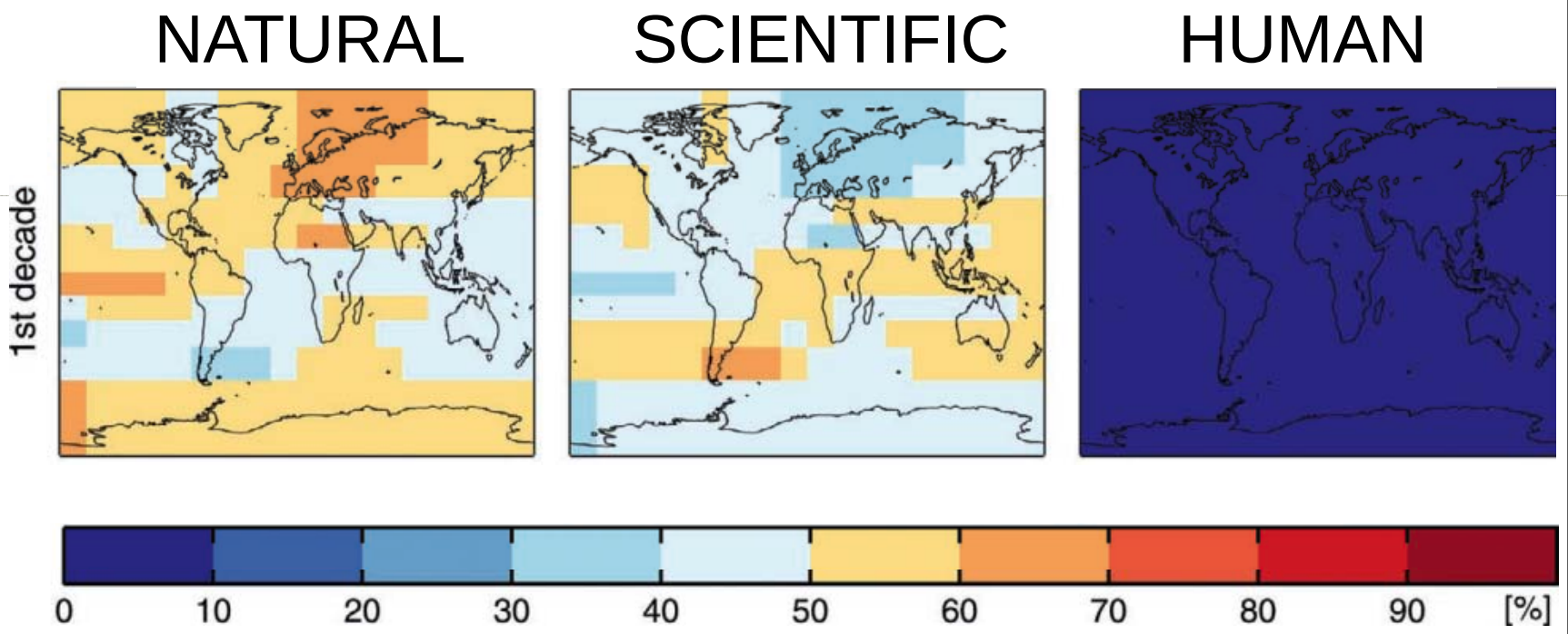
Natural

Scientific

Uncertainty

Human

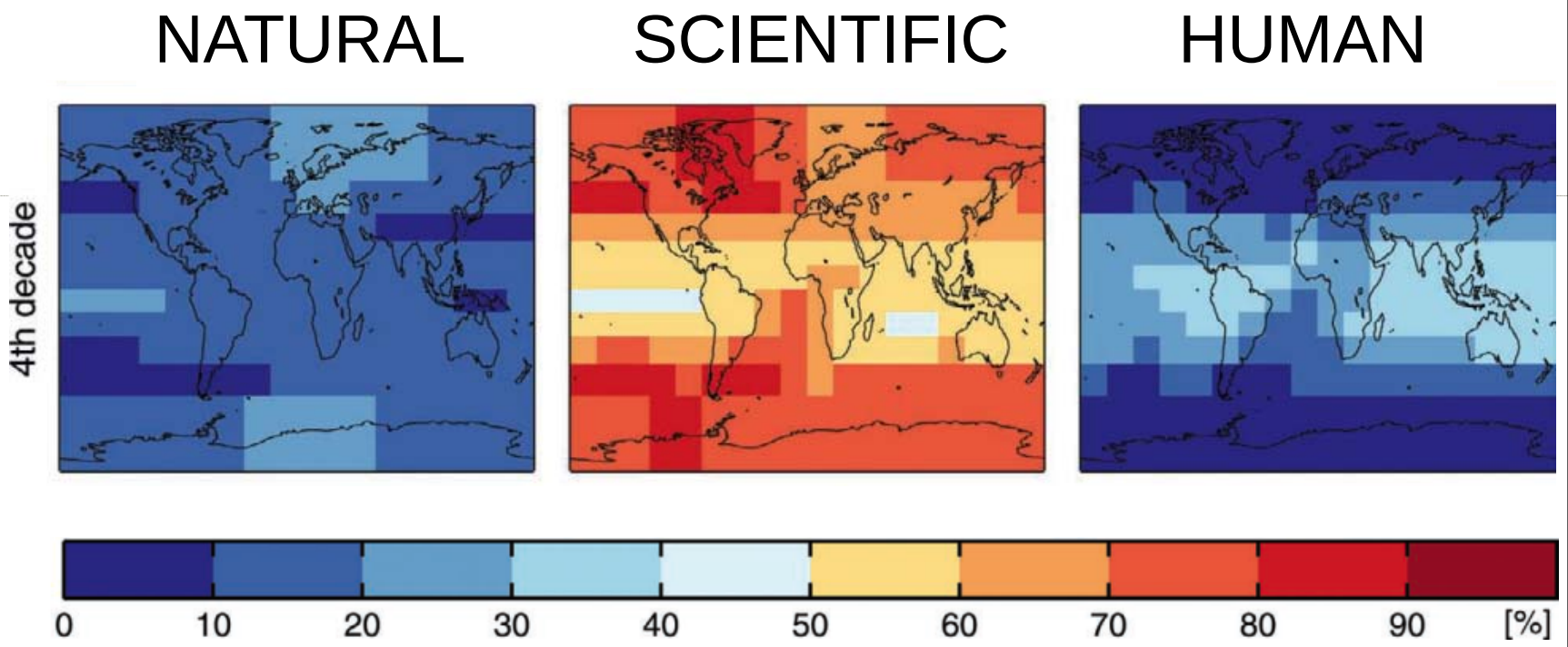
SOURCES OF UNCERTAINTY



+ 10 years

Hawkins & Sutton 2009

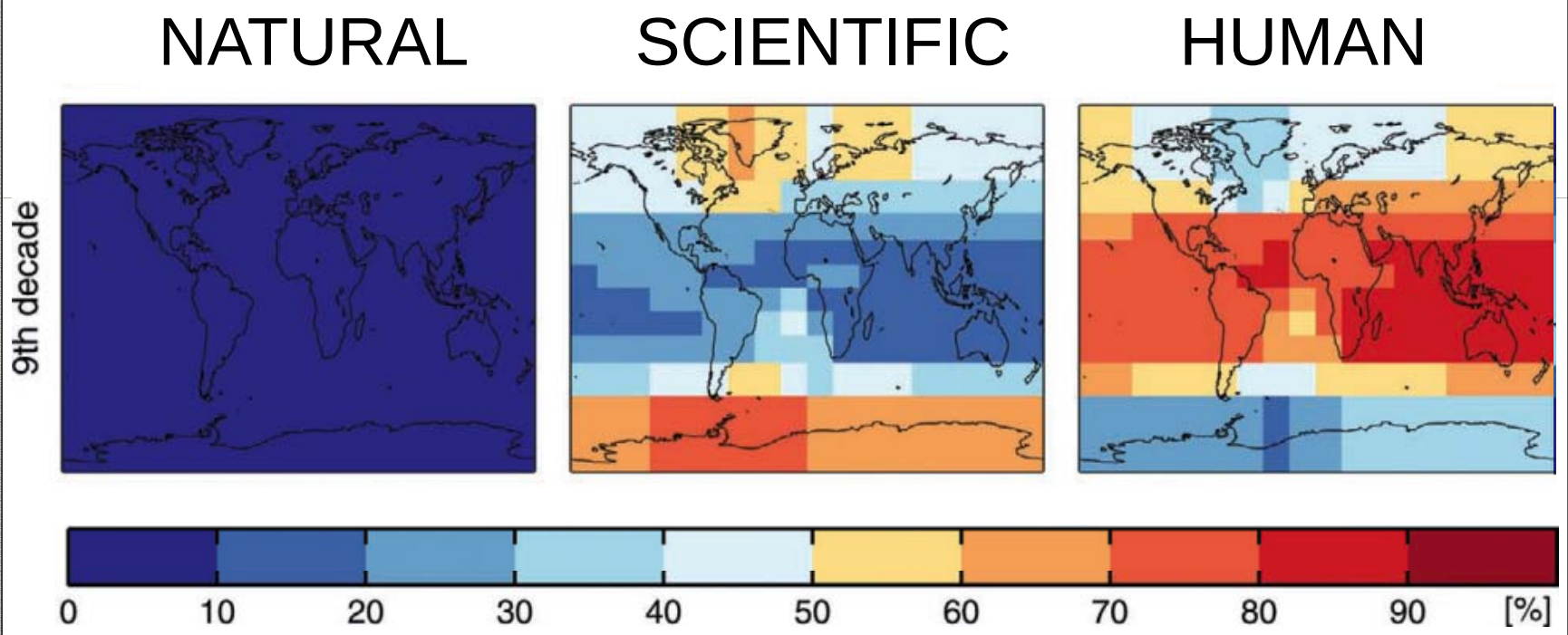
SOURCES OF UNCERTAINTY



+ 40 years

Hawkins & Sutton 2009

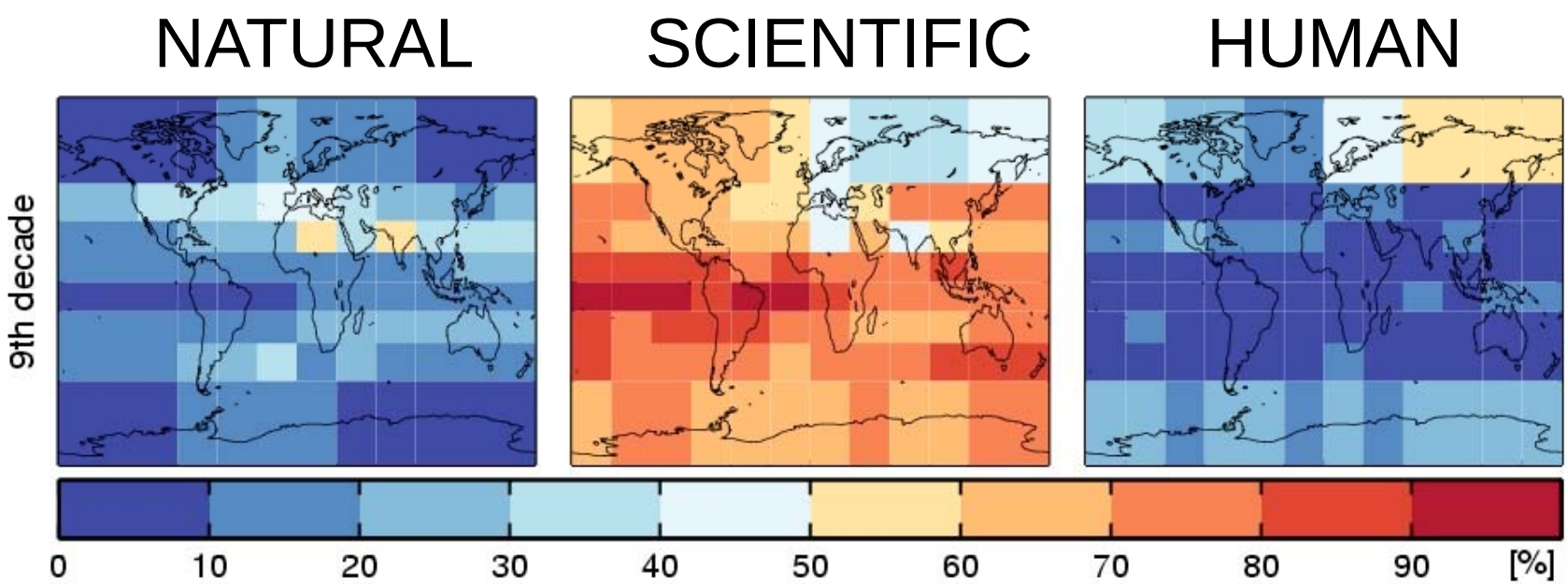
SOURCES OF UNCERTAINTY



+ 90 years

Hawkins & Sutton 2009

SOURCES OF UNCERTAINTY



+ 90 years

Precipitation: Hawkins & Sutton 2011

Why are future projections uncertain?

1. On-going natural variations in climate are chaotic, making it difficult to predict conditions over time scales shorter than a decade

Natural Variability

NEAR-TERM

- **Natural variability** is the greatest source of uncertainty in projections for the next 20-30 years
- **Global mean temperature** likely to increase by 0.5 to 1^{o}C
- **Recommendation**: use multiple simulations to cover likely range of natural variability

Why are future projections uncertain?

2. We don't know exactly how sensitive the climate system is to these emissions
3. Our ability to simulate the climate system is limited and incomplete, particularly at the local to regional scale

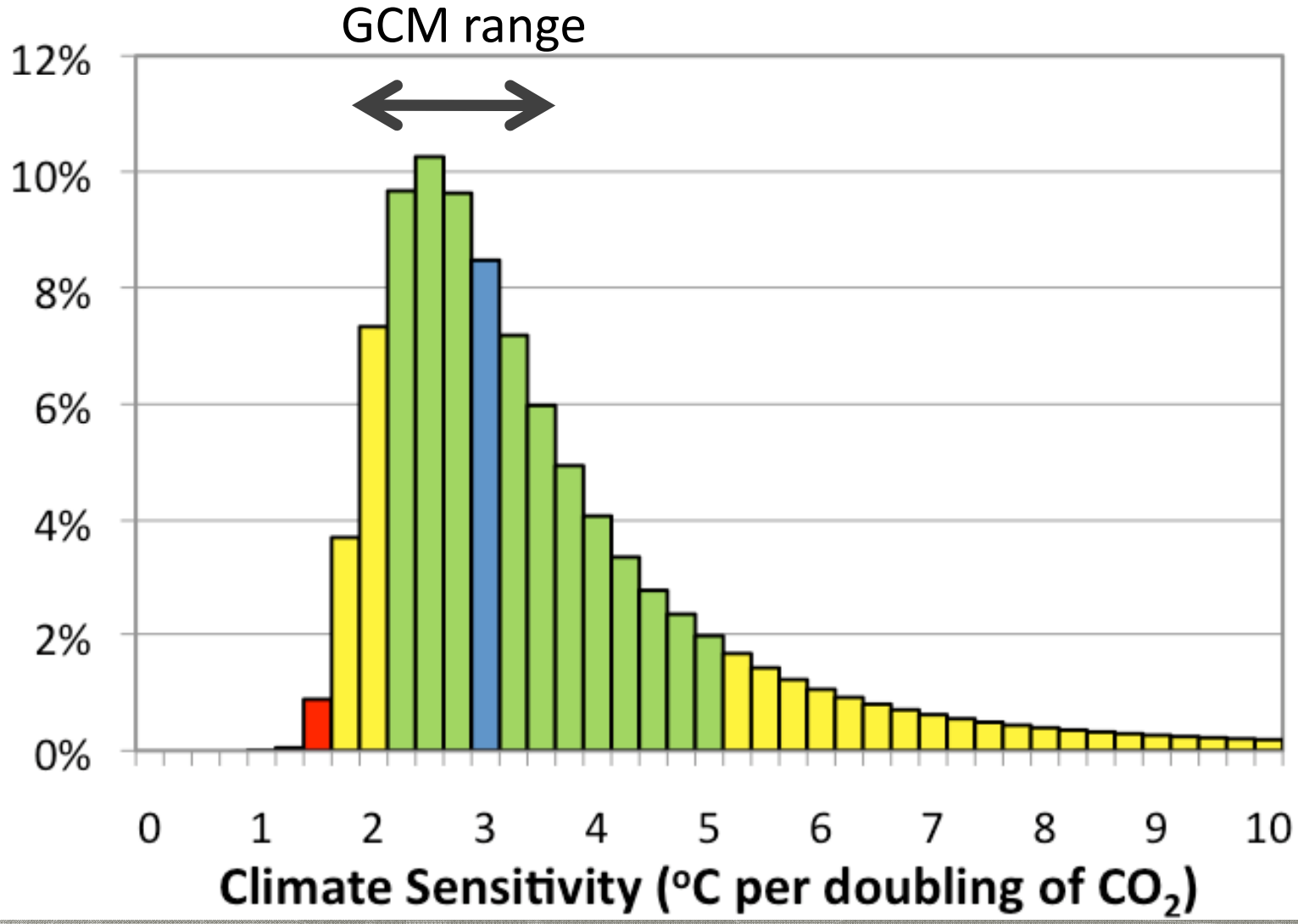
Scientific Uncertainty

2. How sensitive is the planet to what we're putting into the atmosphere?

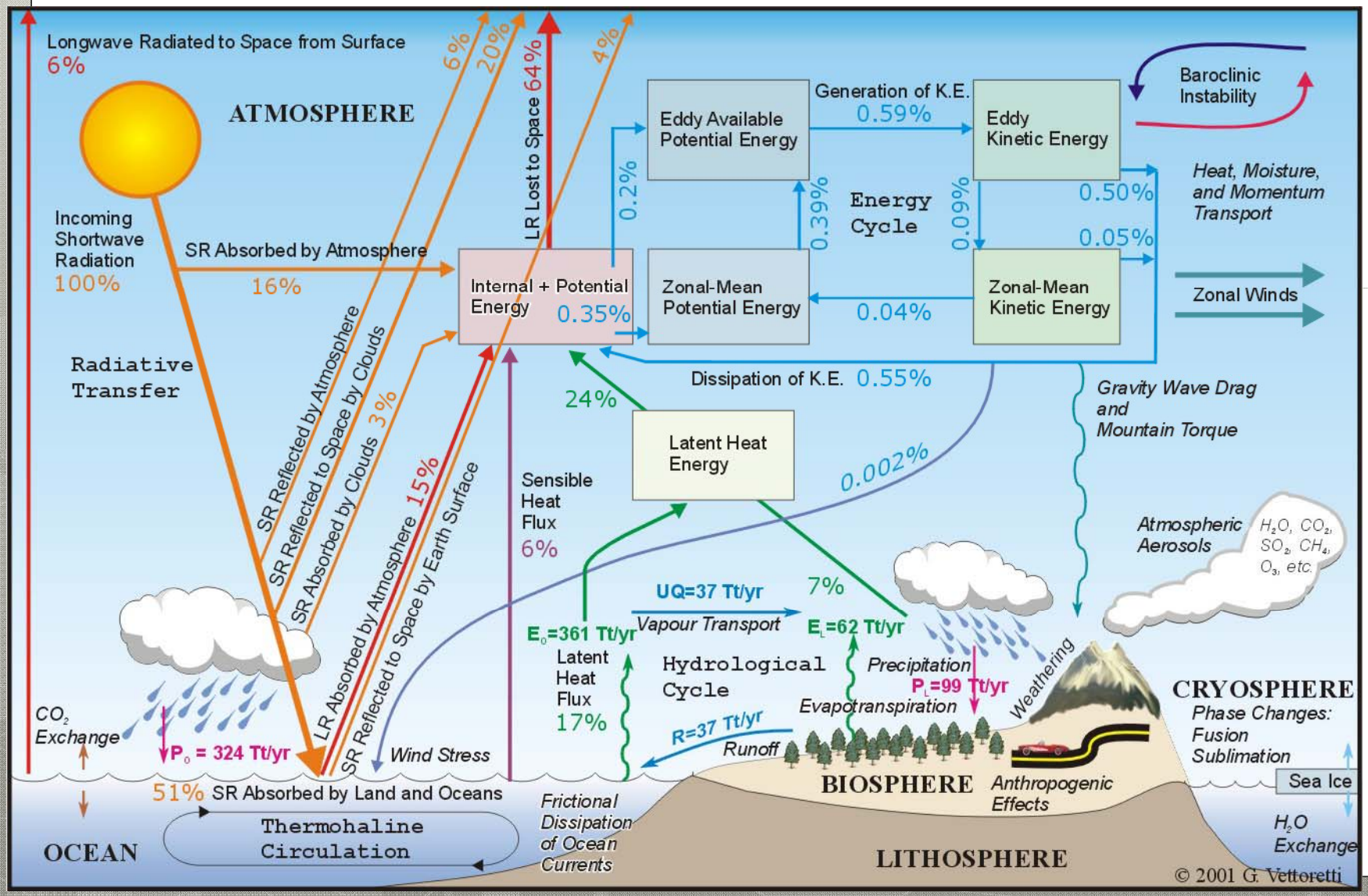
CLIMATE SENSITIVITY is defined as the long-term global mean temperature increase associated with a doubling of the atmospheric concentration of carbon dioxide

Includes the response of water vapor, clouds, sea ice, snow cover, and surface ocean to a warming planet.

Likely distribution of climate sensitivity



The basic physics of the climate system

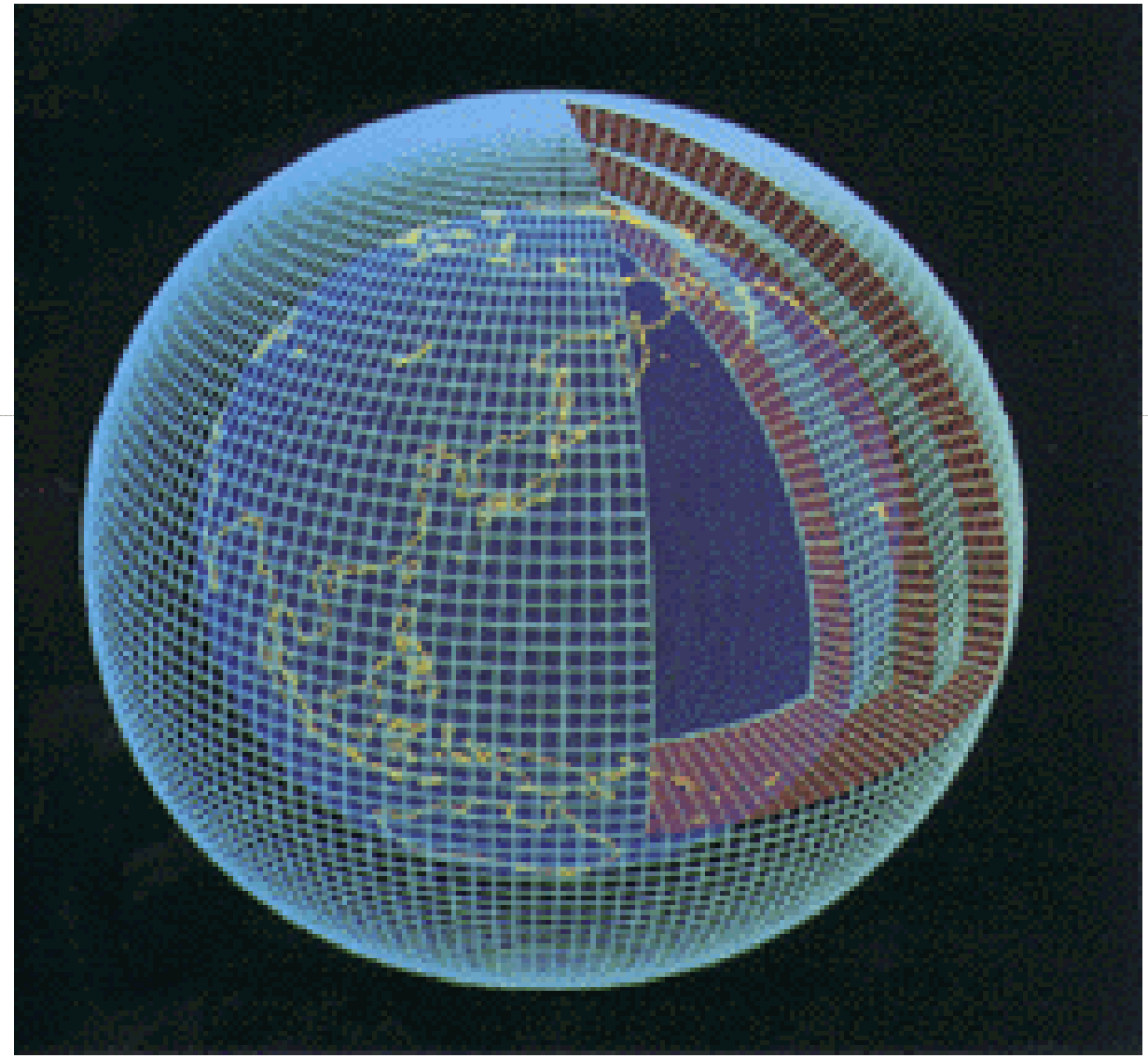


GCM =

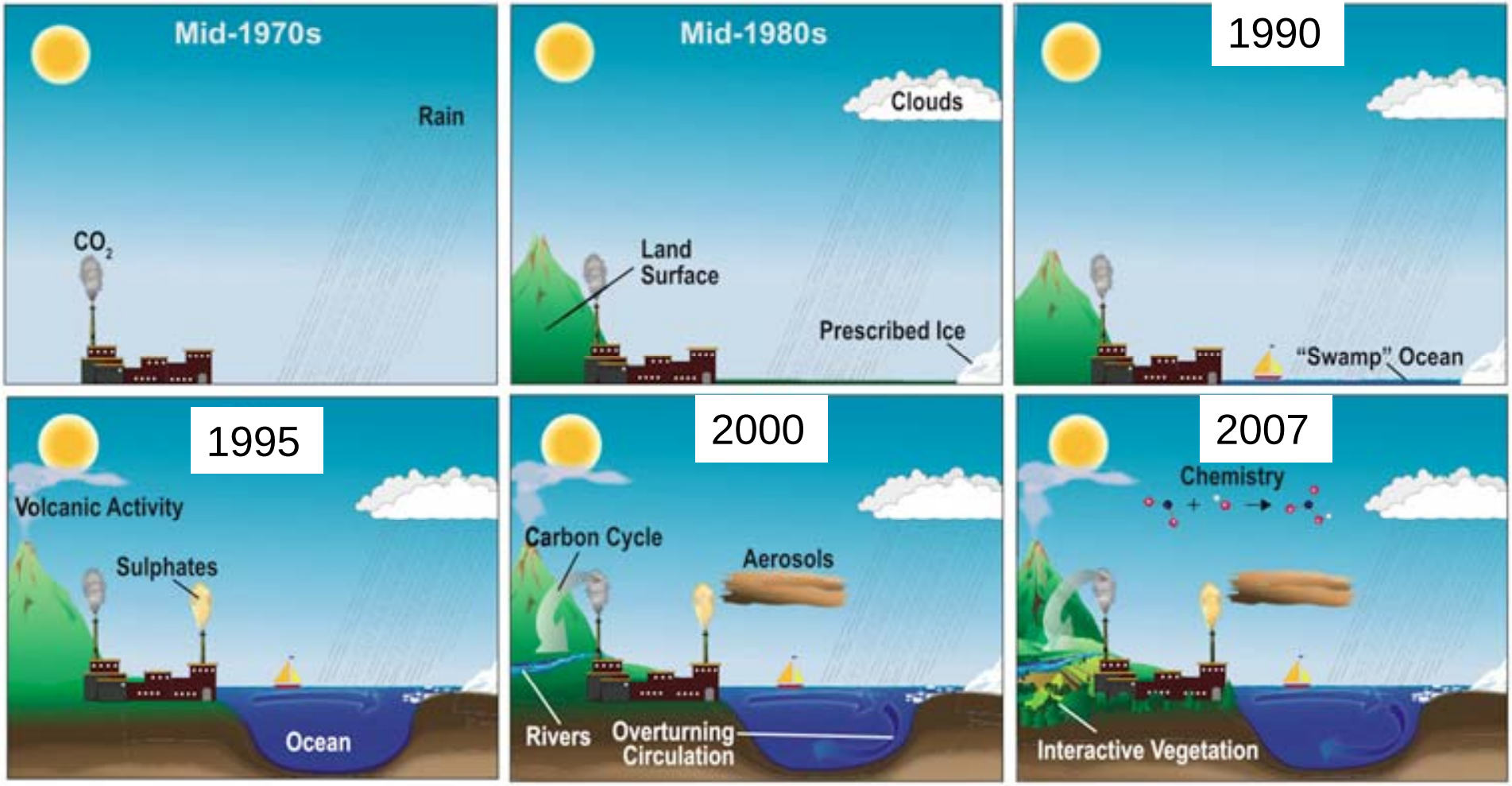
Global Climate Model

or

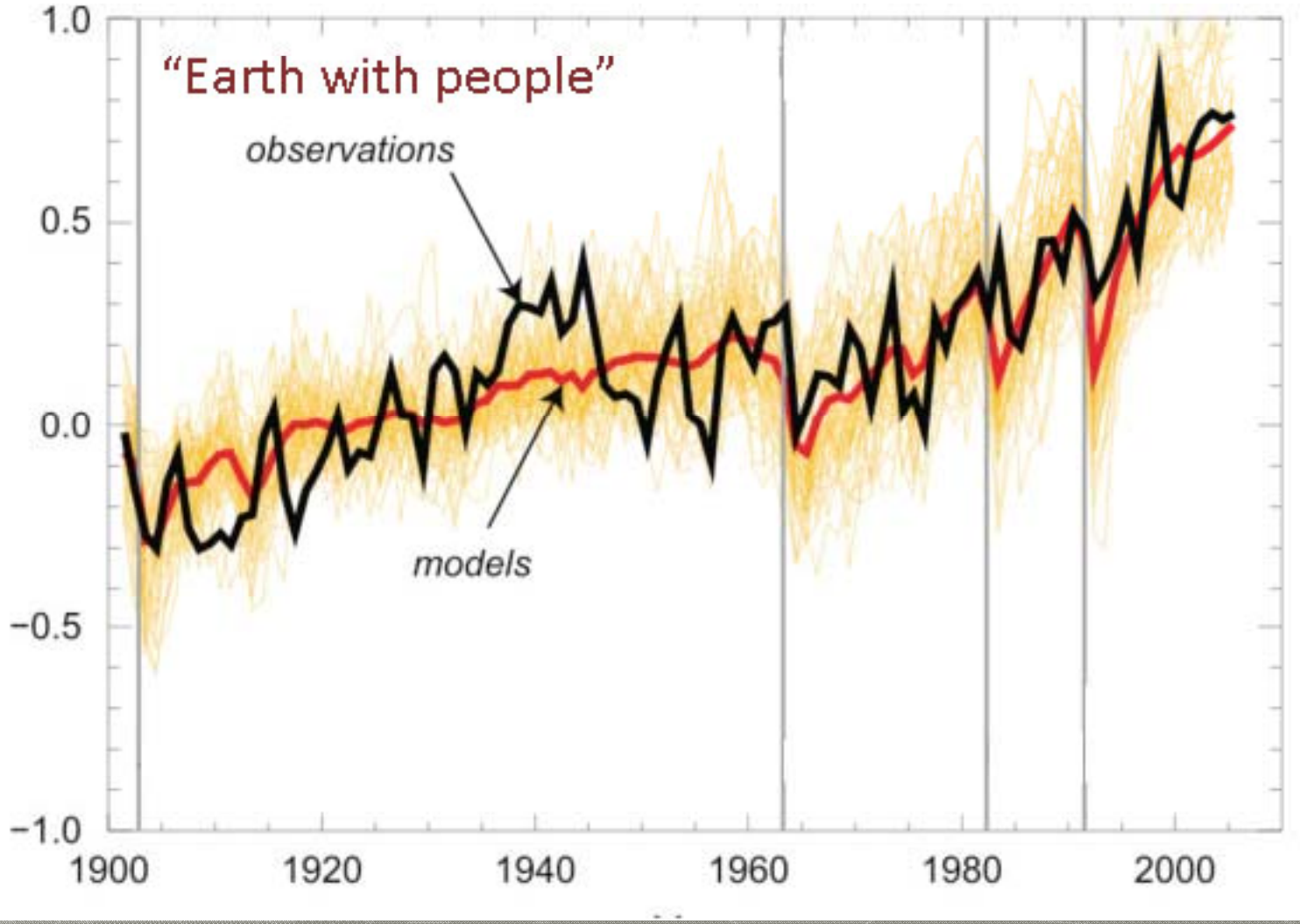
General Circulation Model



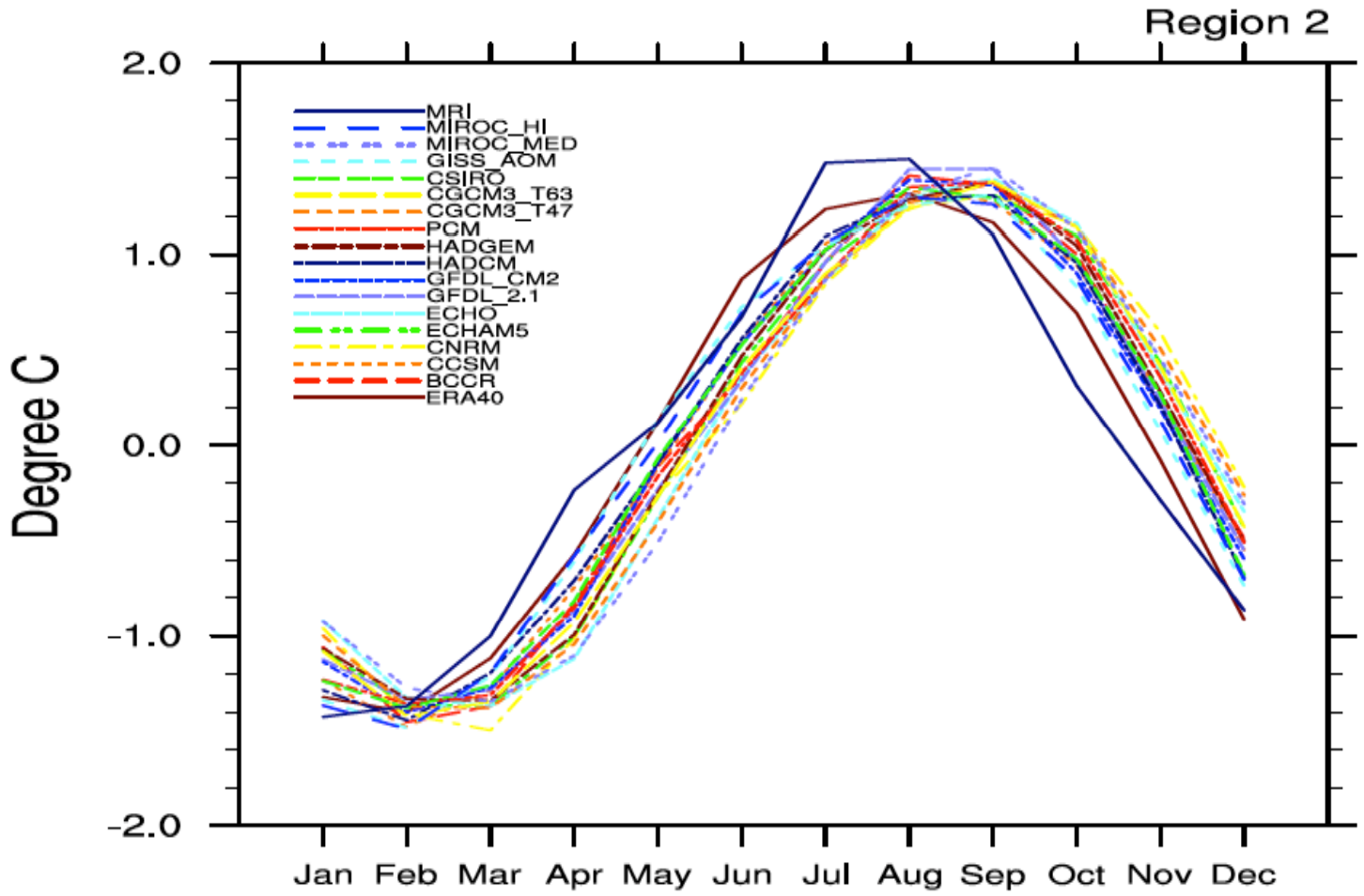
The evolution of climate models



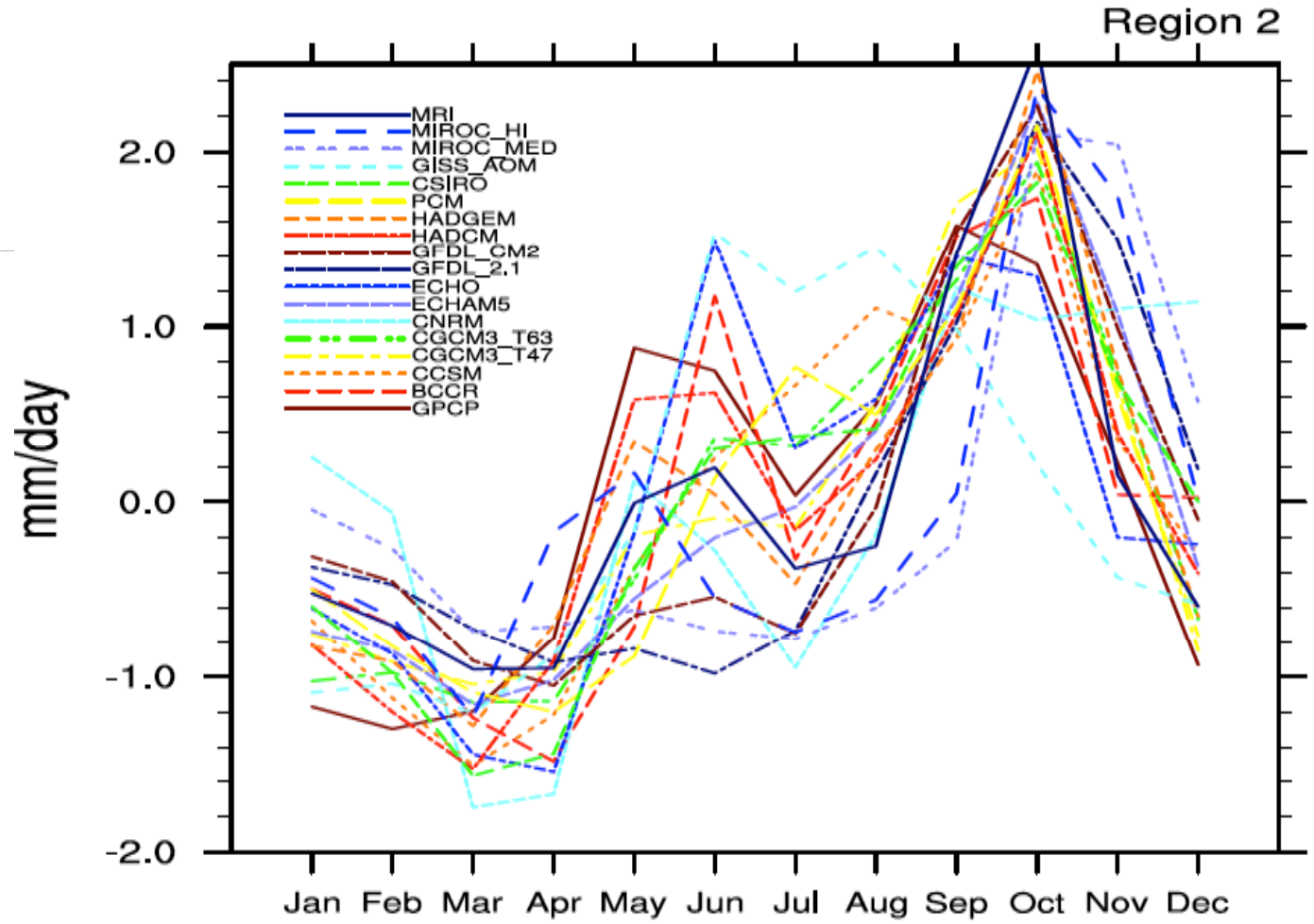
How well do models simulate global temperature?



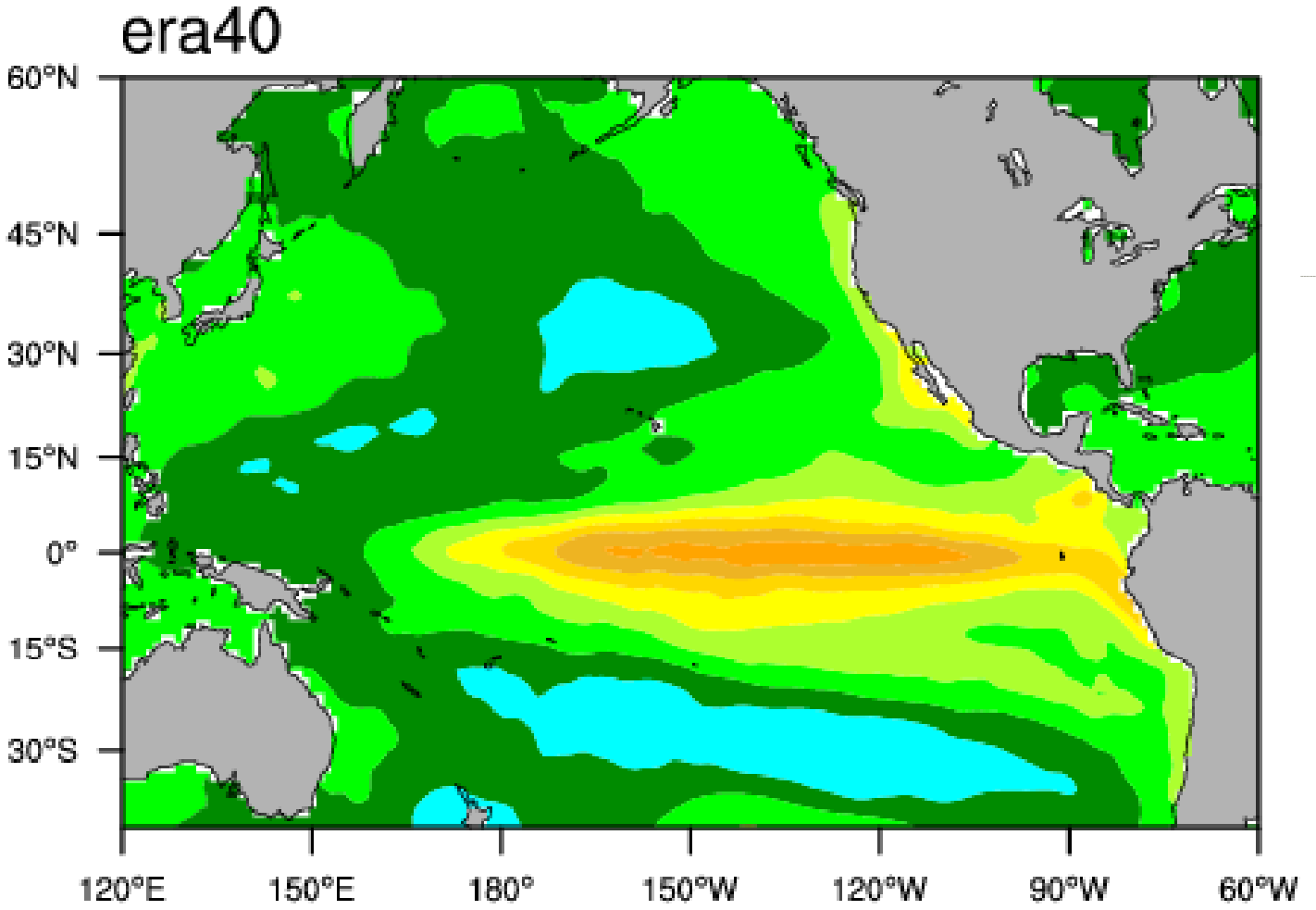
Annual Cycle of Temperature over NE Caribbean



Annual Cycle of Precipitation over NE Caribbean

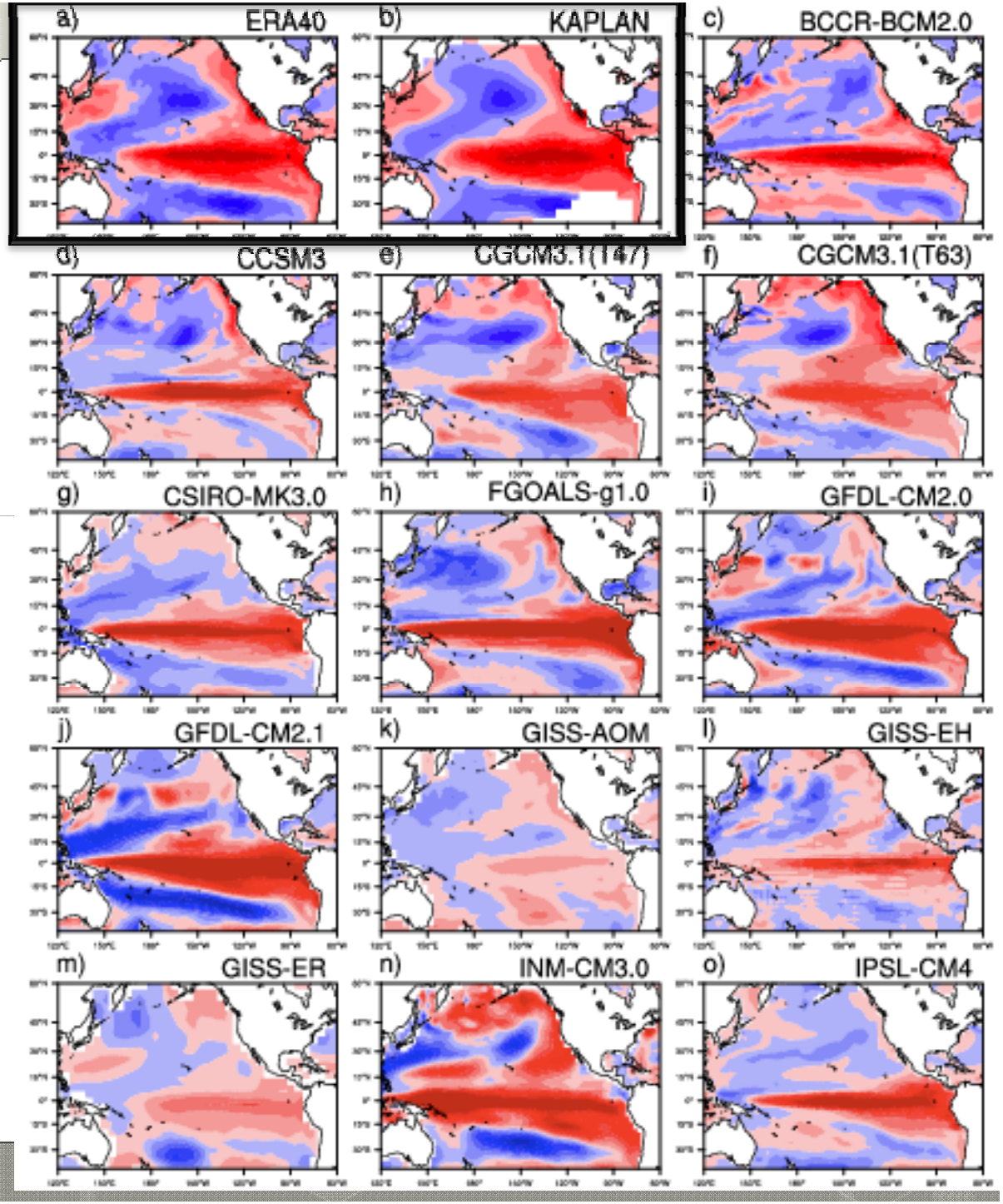


What about El Nino?



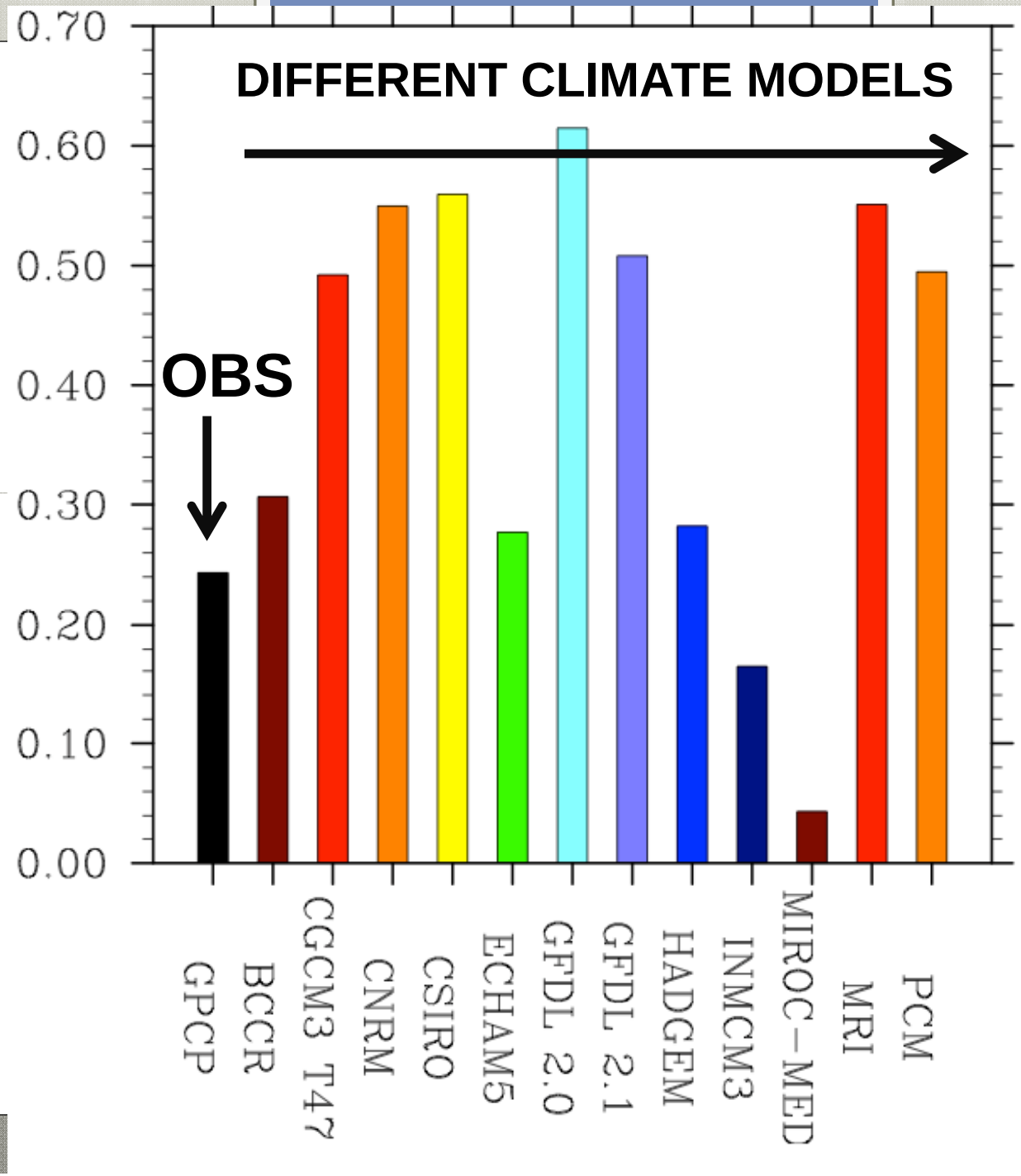
ENSO

- **All models capture a recognizable ENSO pattern**
- Most models too strong, warm tongue extends too far west



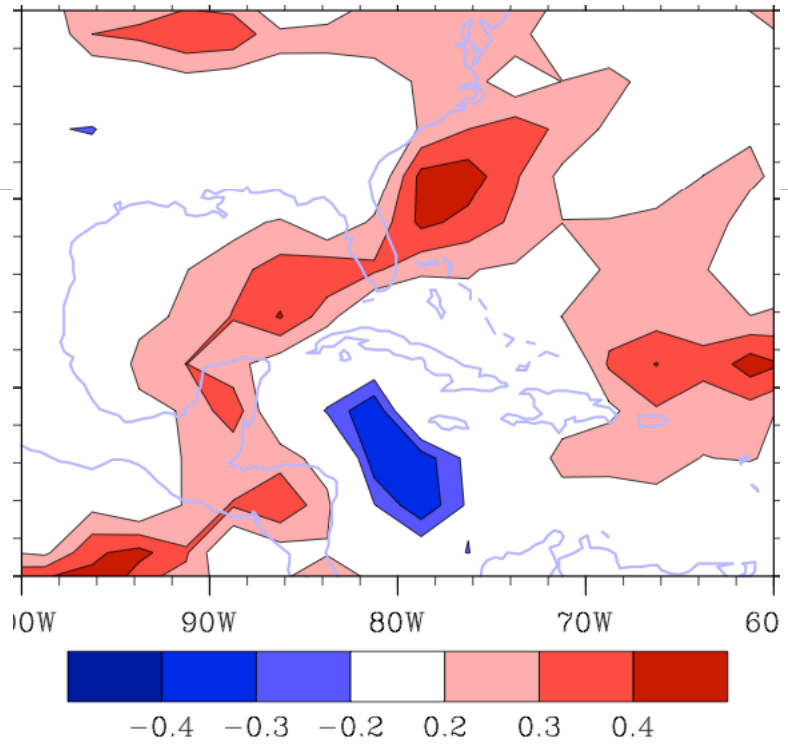
Stoner, Hayhoe 2009

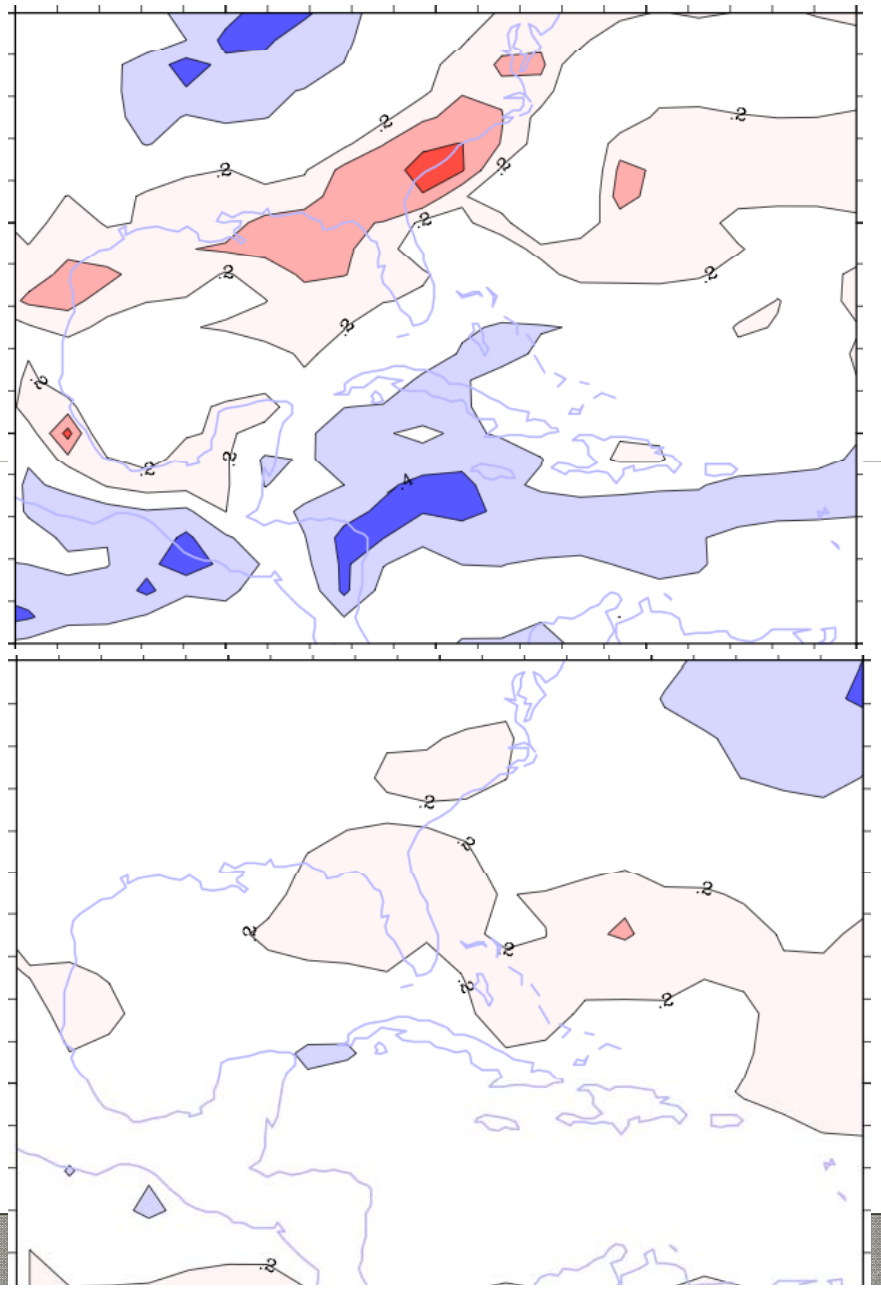
ALL models simulate positive effect of El Nino on rainfall, but ...



MODELS --->

OBS





MID-CENTURY

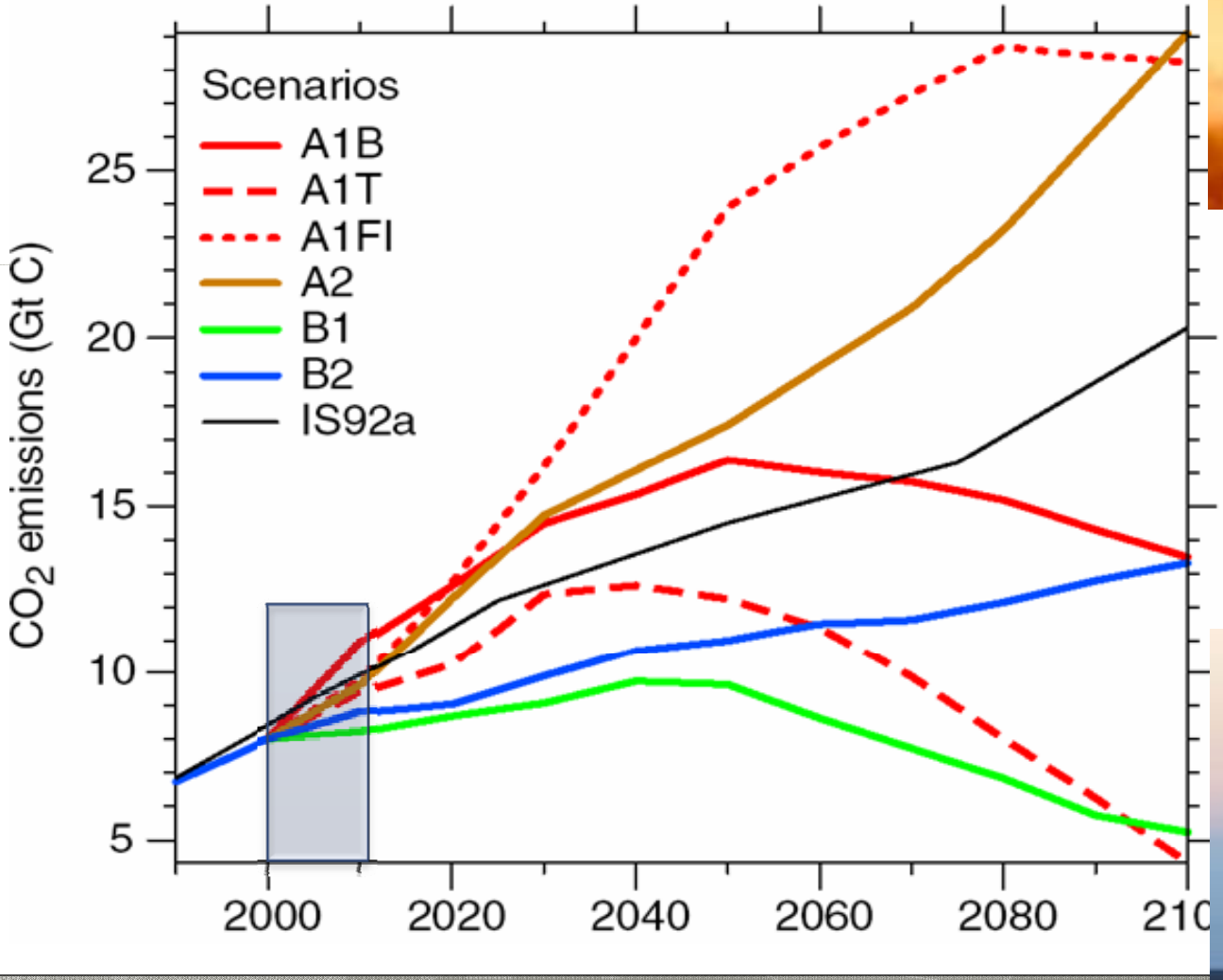
- **Scientific uncertainty** is the greatest source of uncertainty in projections for next 40-60 yrs
- **Global mean temperature** is likely to increase by 1-3^{o}C
- **Recommendation**: use simulations from many, many climate models to cover an adequate range of climate sensitivity and model uncertainty.
- Only **remove** climate models if it can be shown that they do not reproduce large-scale circulation features essential to your analysis.

Why are future projections uncertain?

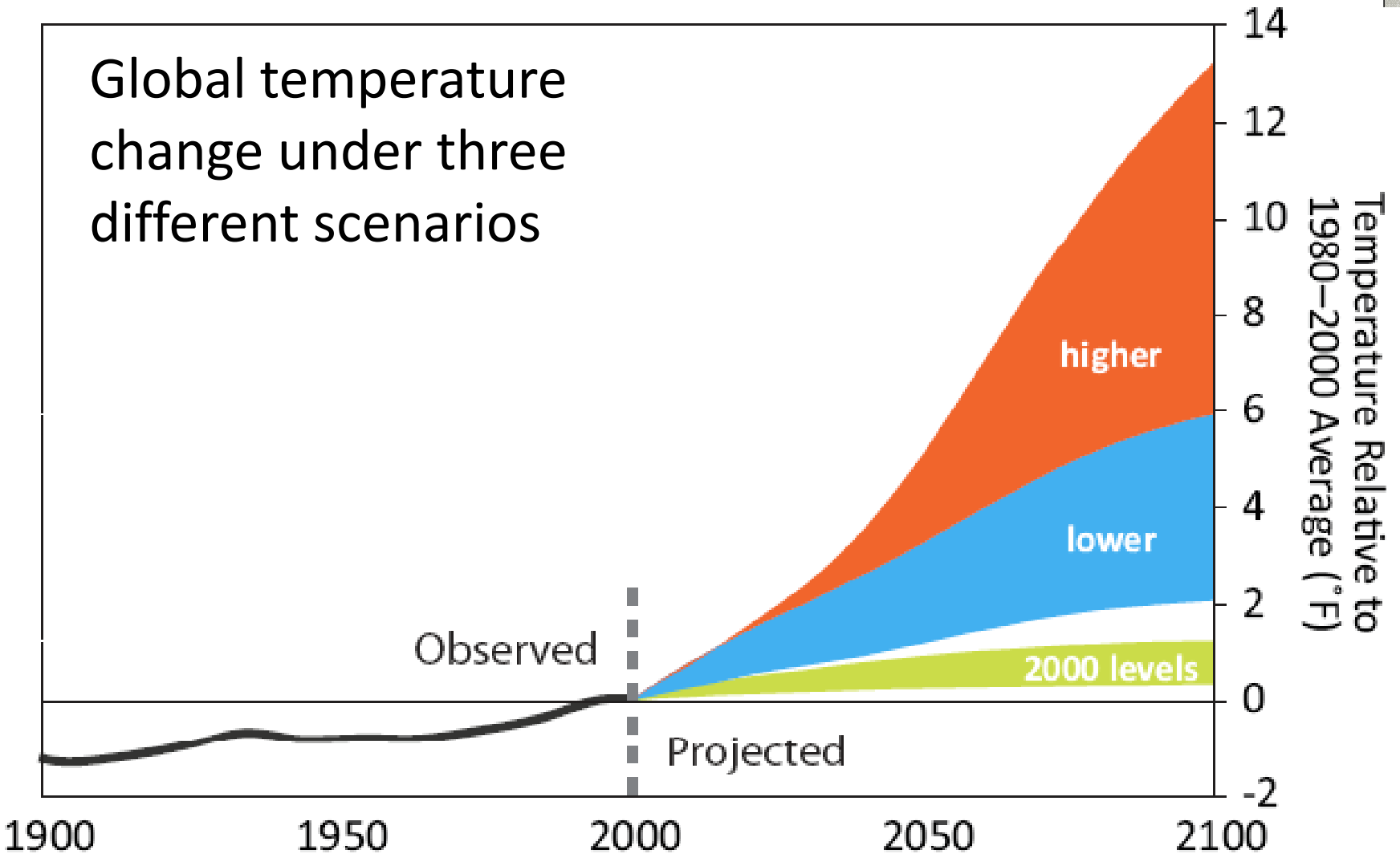
4. We don't know what future emissions from human activities will be

Human Uncertainty

EMISSION SCENARIOS



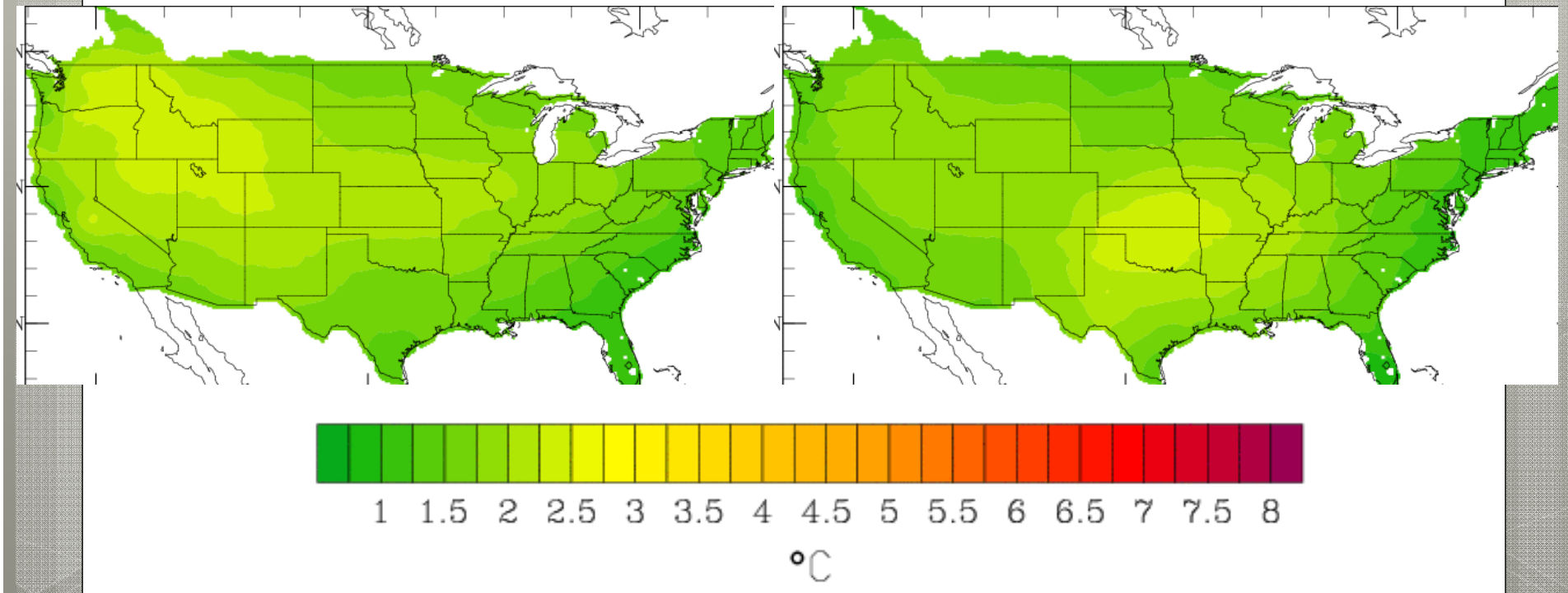
What can we expect in the future?



Summer Temperature Change

A1FI (higher)

B1 (lower)



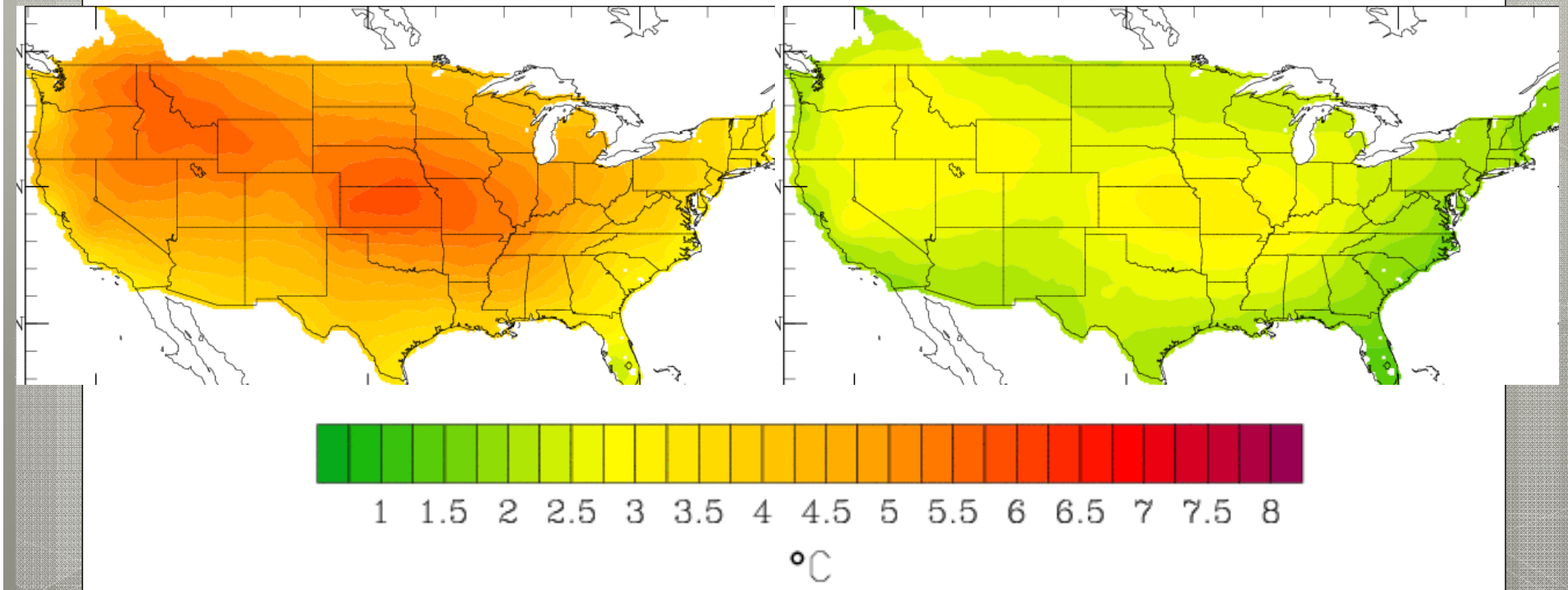
2010-2039

Source: K. Hayhoe for USGCRP (2009)

Summer Temperature Change

A1FI (higher)

B1 (lower)



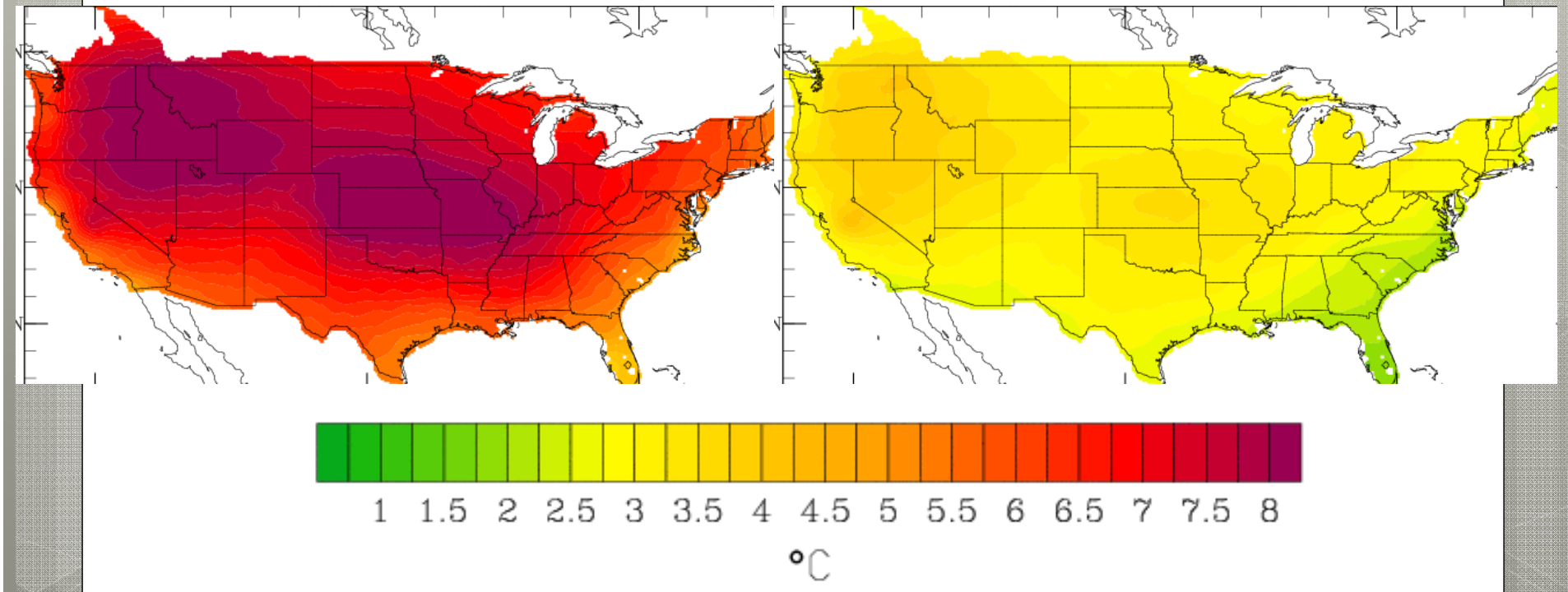
2040-2069

Source: K. Hayhoe for USGCRP (2009)

Summer Temperature Change

A1FI (higher)

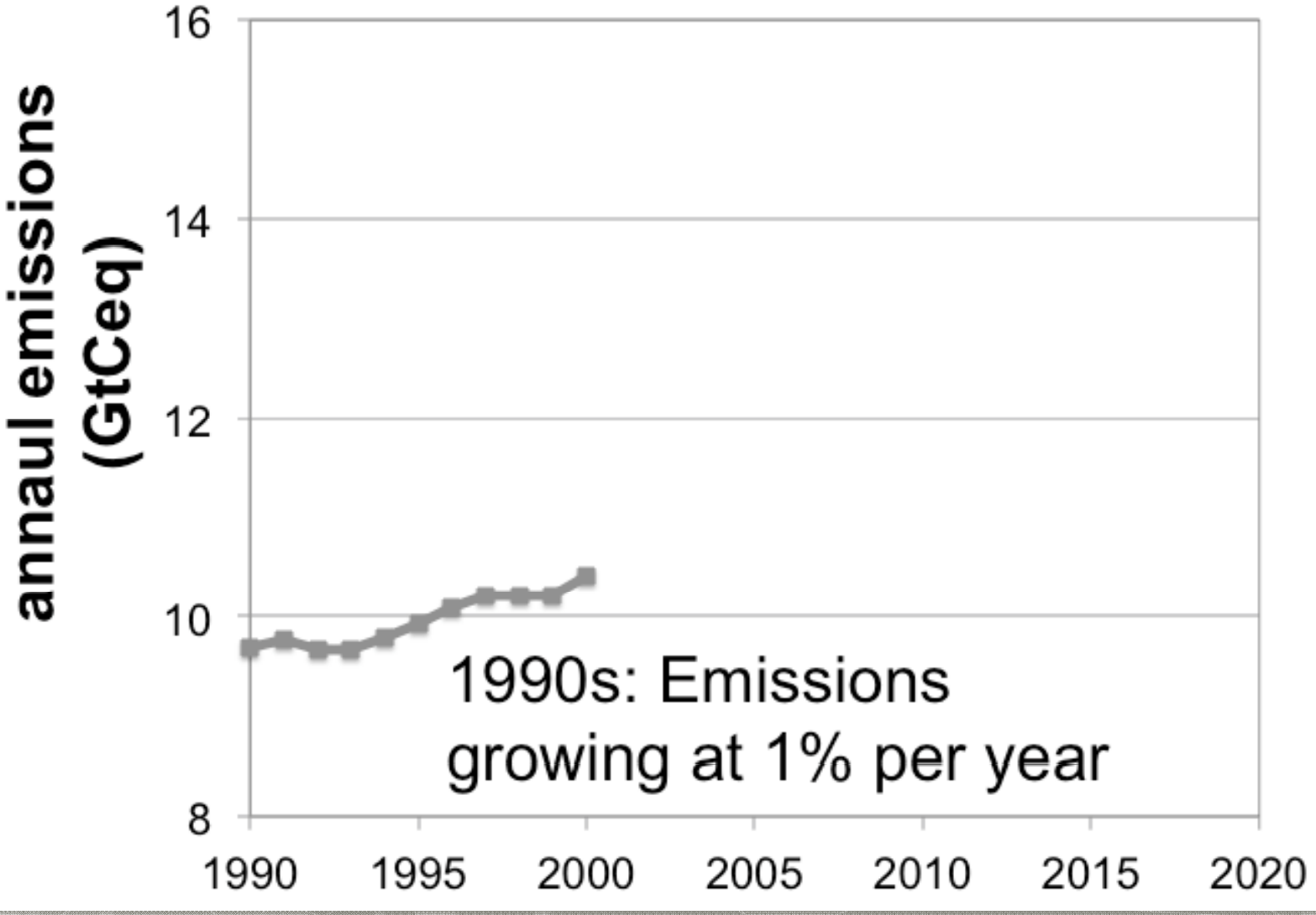
B1 (lower)



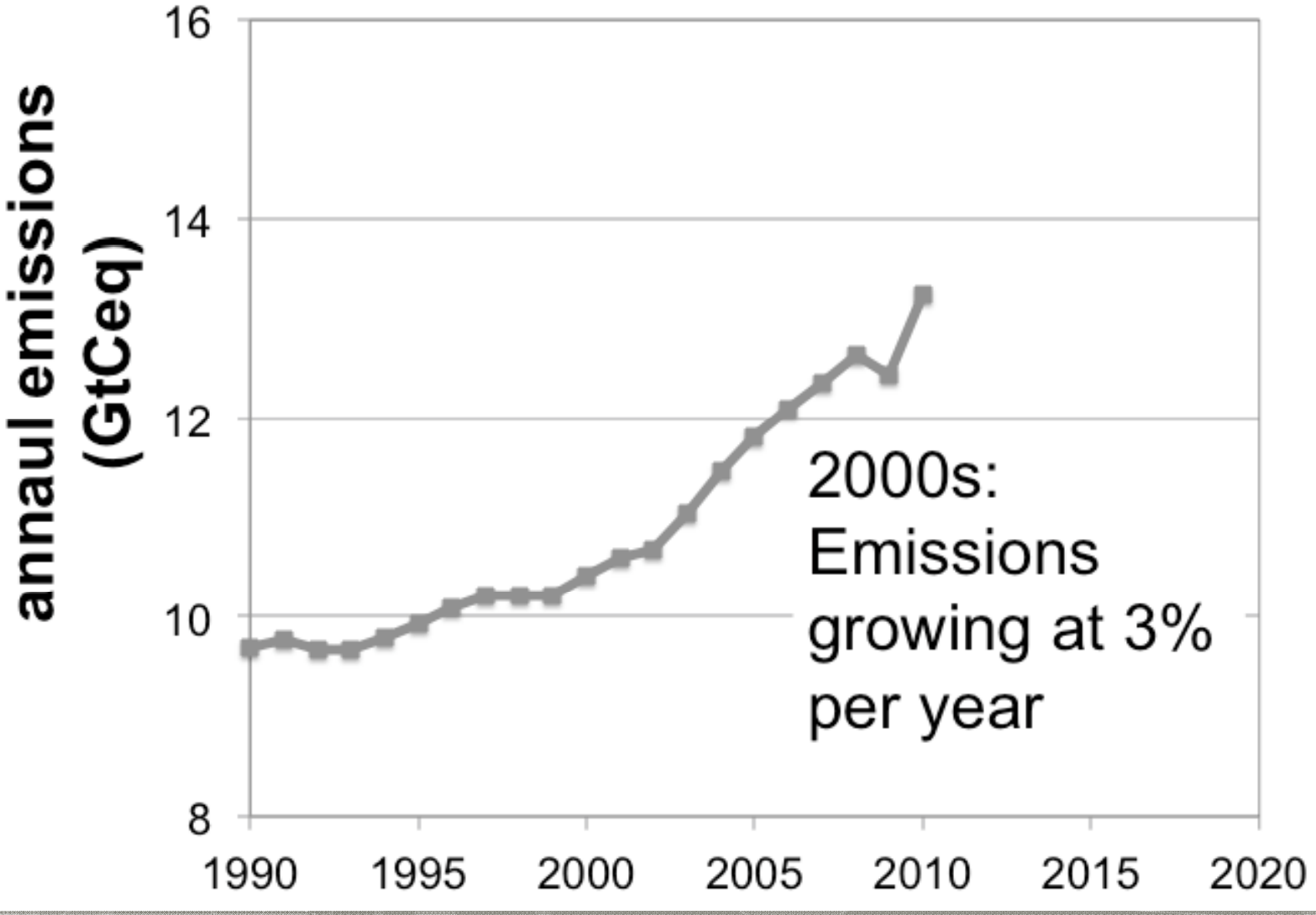
2070-2099

Source: K. Hayhoe for USGCRP (2009)

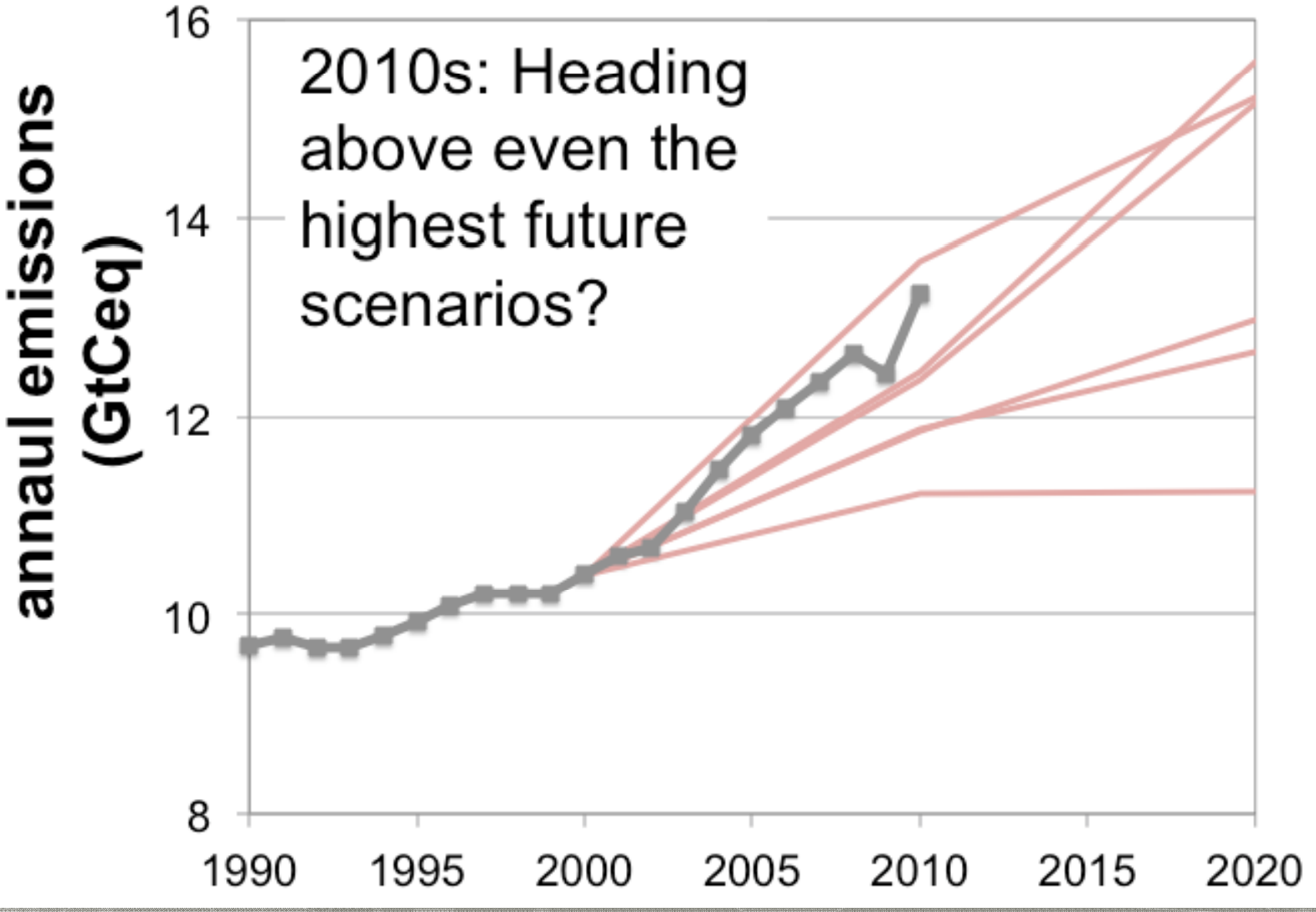
Emissions of heat-trapping gases



Emissions of heat-trapping gases



Emissions of heat-trapping gases



END-OF-CENTURY

- **Human choices** are greatest source of uncertainty in temperature projections beyond 60-70 yrs
- **Scientific uncertainty** is still greatest source of uncertainty in precipitation beyond 60-70 yrs for the Caribbean
- **Global mean temperature** likely between +2-6^{o}C
- **Recommendation**: use multiple scenarios covering a range of possible futures

Why are future projections uncertain?

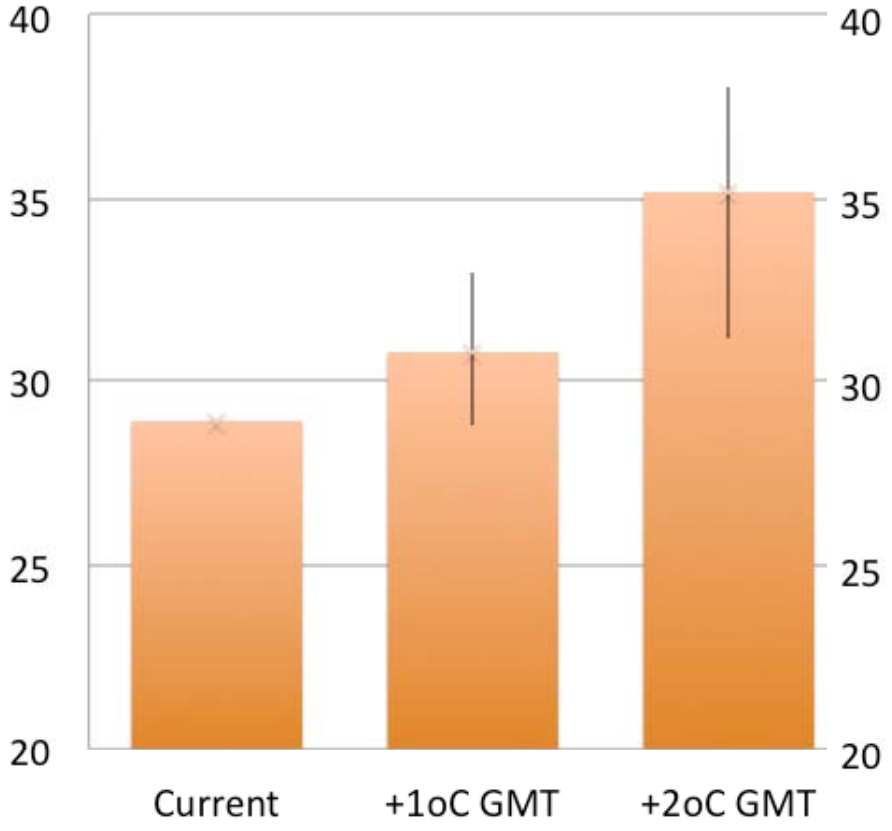
1. On-going natural variations in climate are chaotic, making it difficult to predict conditions over time scales shorter than a decade
2. We don't know exactly how sensitive the climate system is to these emissions
3. Our ability to simulate the climate system is limited and incomplete, particularly at the local to regional scale
4. We don't know what future emissions from human activities will be
5. Each location and region responds to global change in a different way

WHAT CLIMATE CHANGE MEANS FOR PUERTO RICO

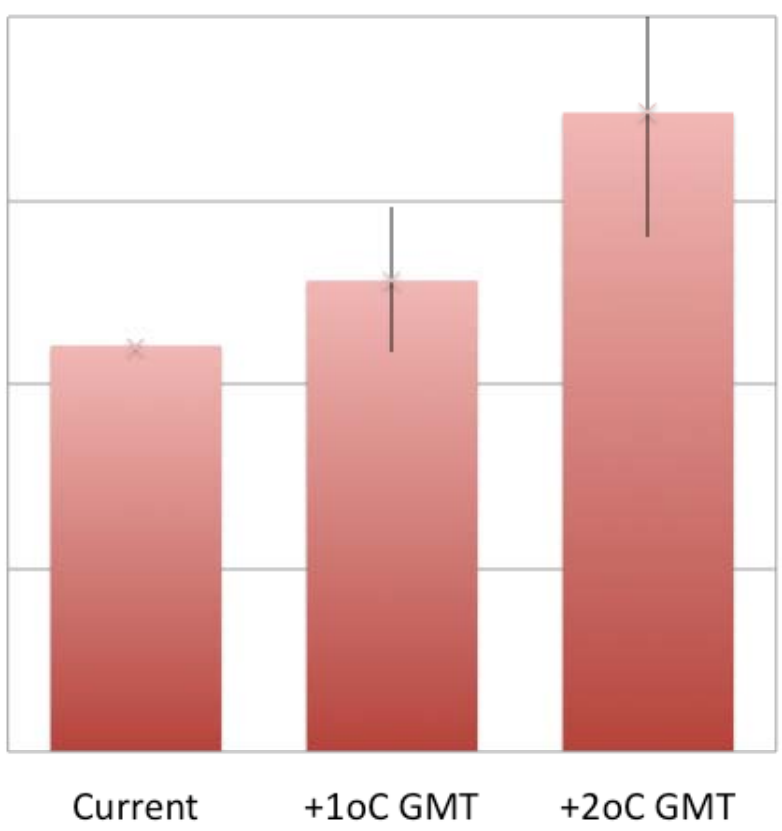
PART FOUR

Daily Maximum Temperature

DRY SEASON

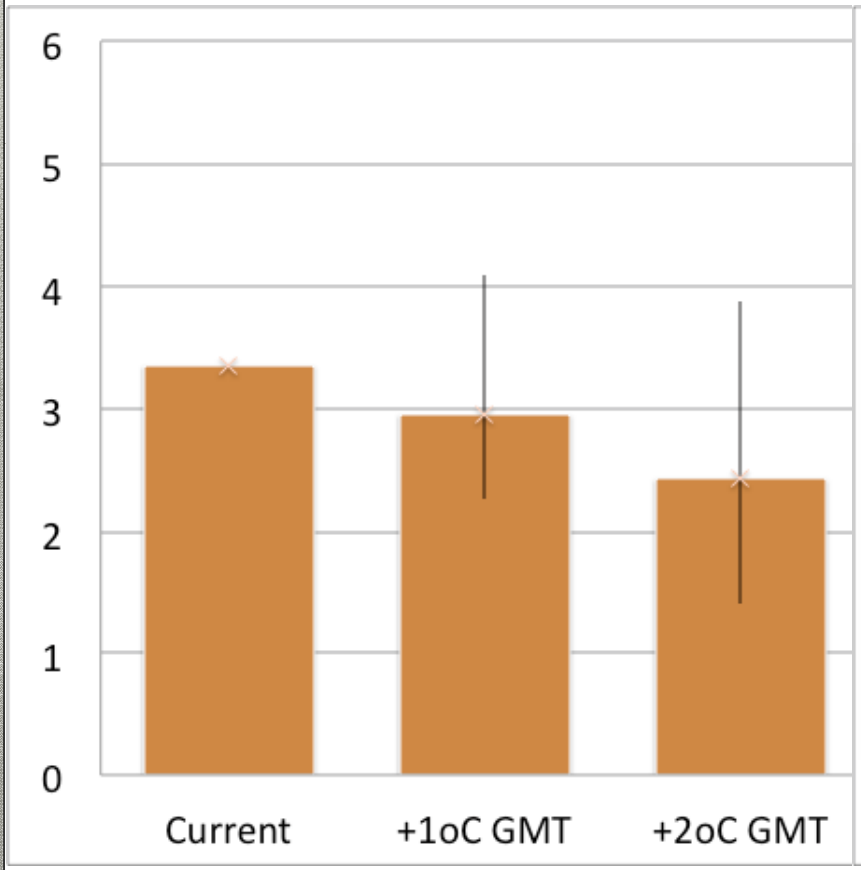


WET SEASON

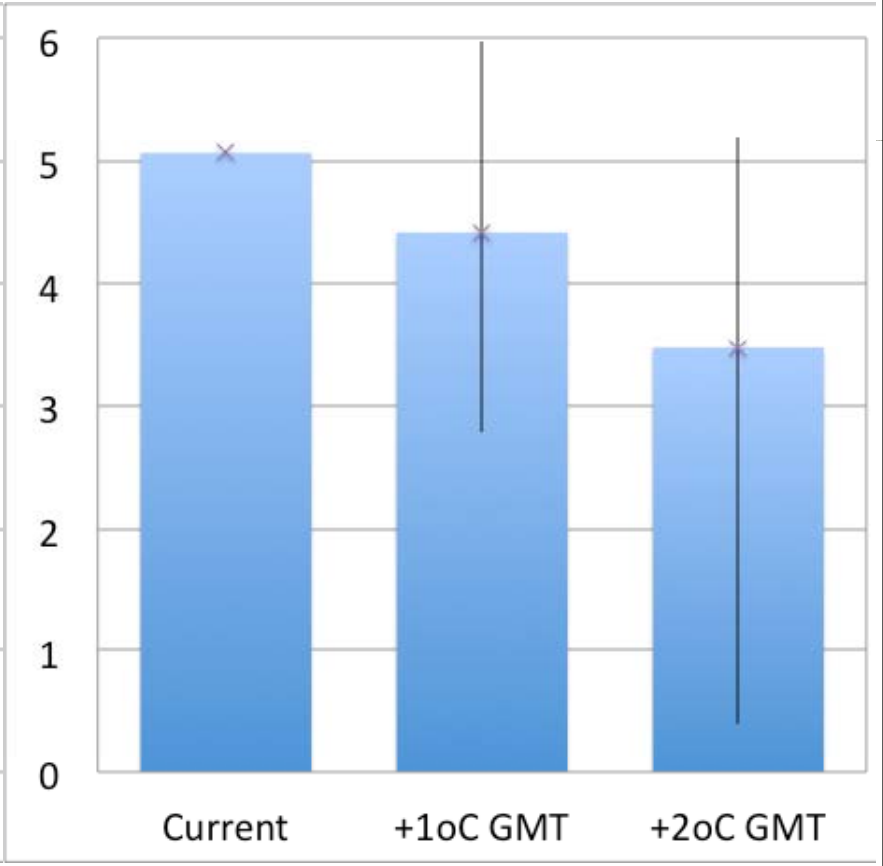


Average Daily Precipitation

DRY SEASON

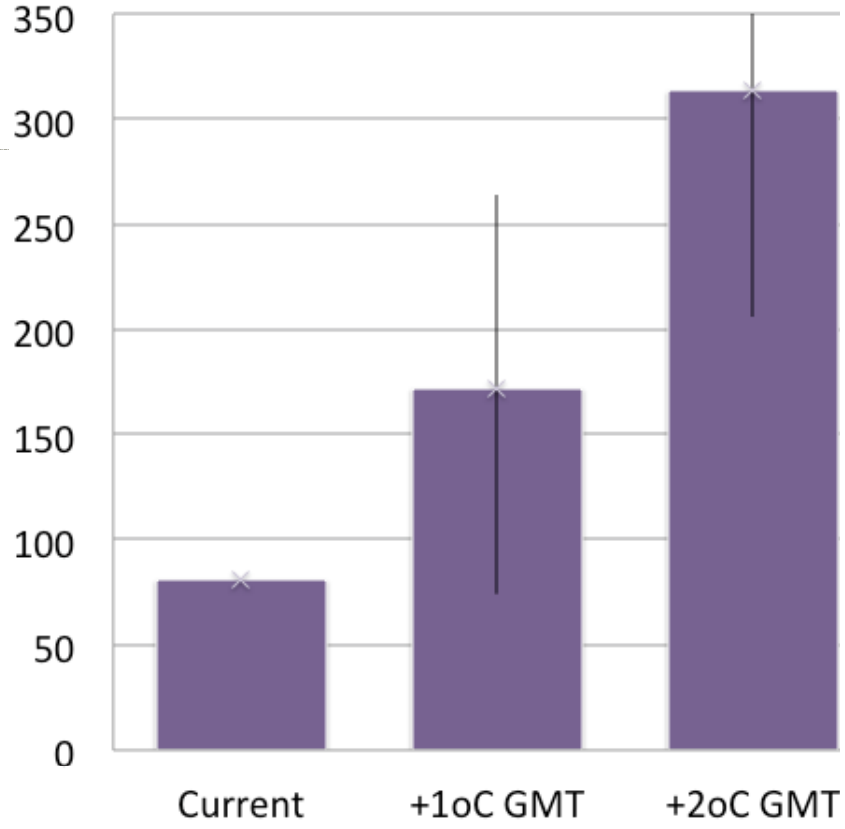


WET SEASON

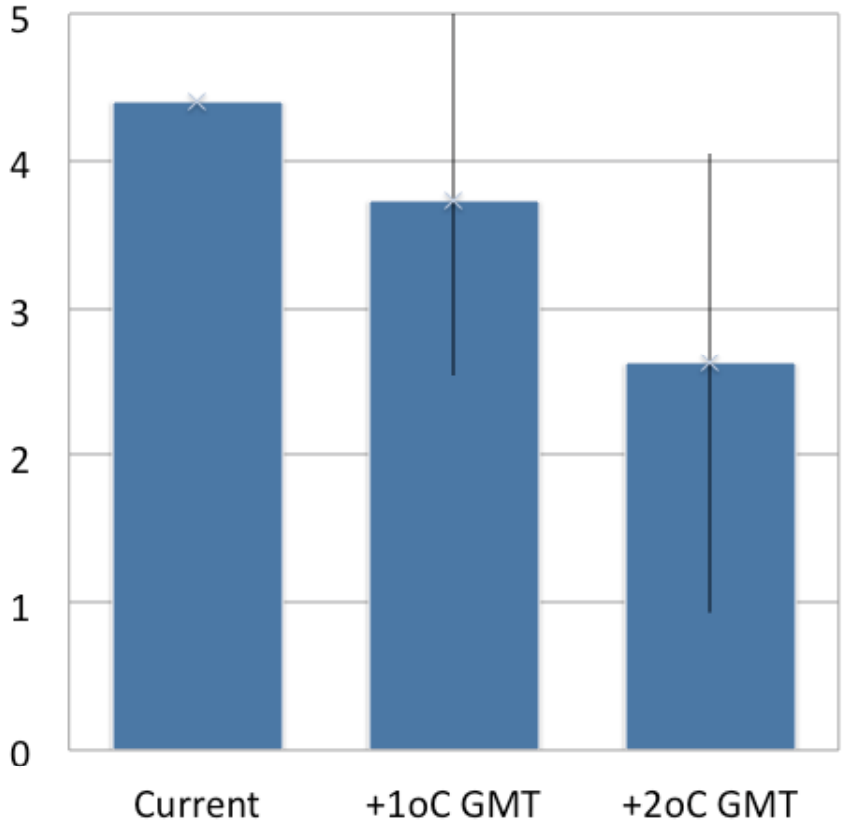


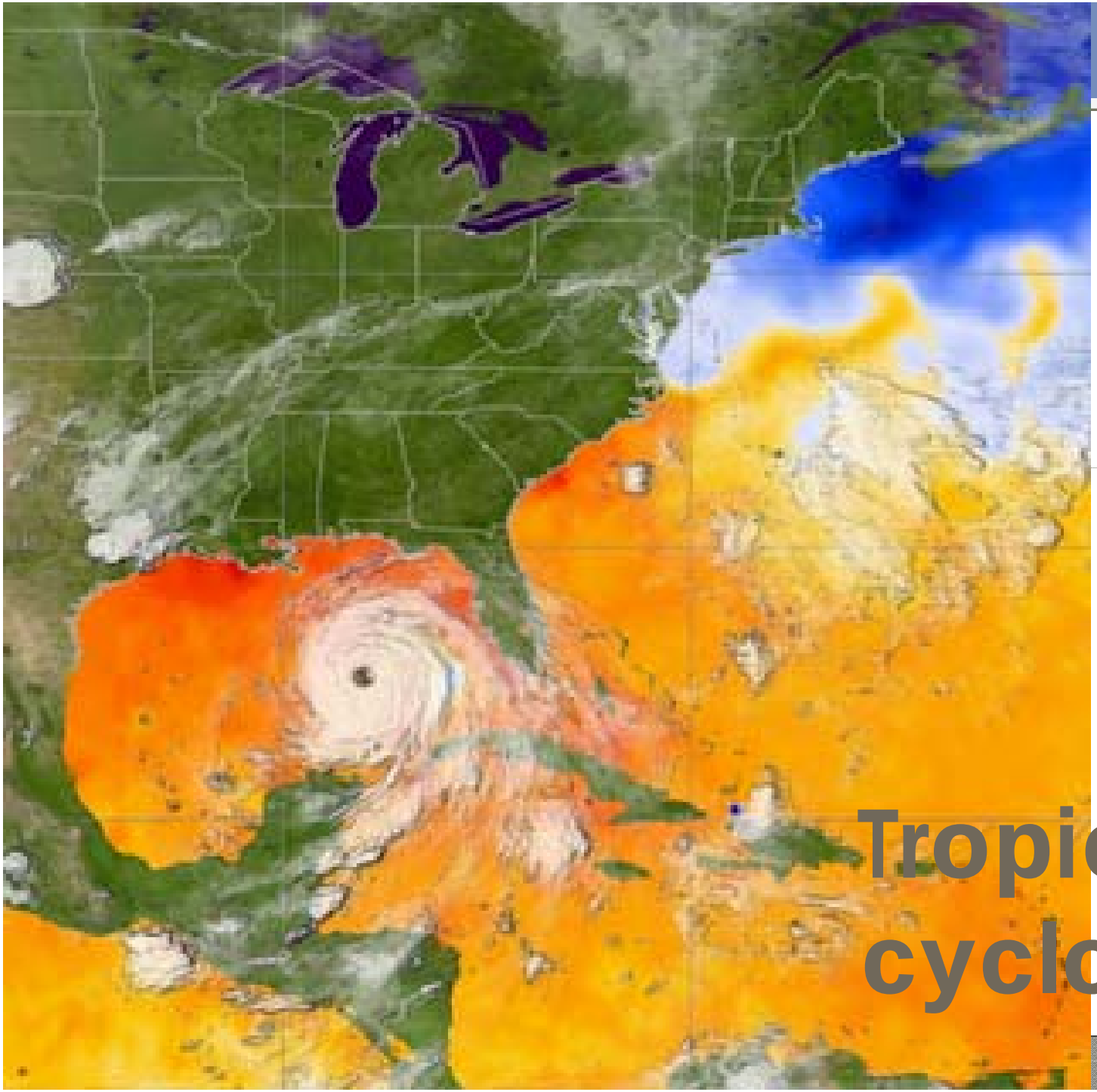
Daily Extremes

Days with TX > 90oF



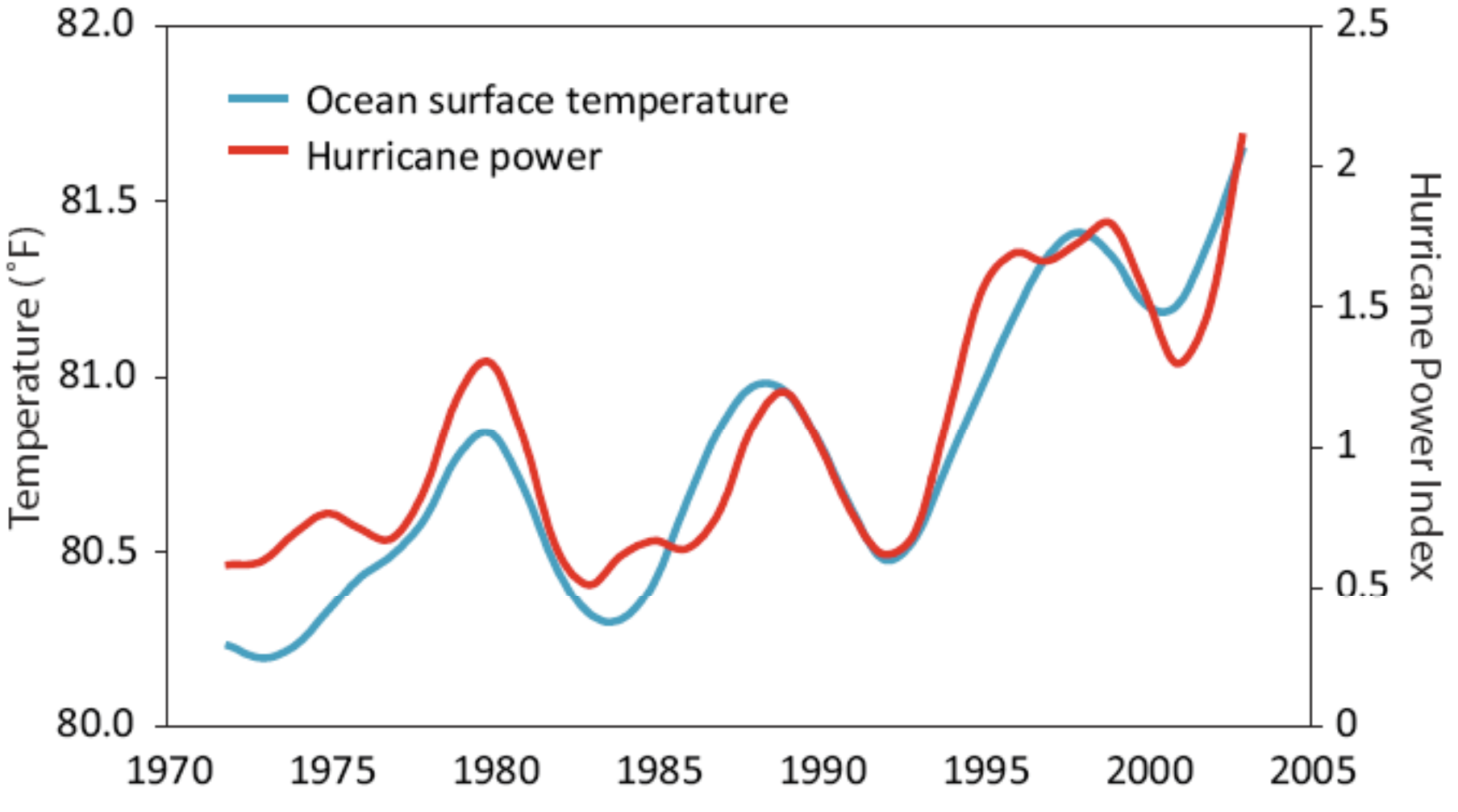
Days with PR > 2”





Tropical cyclones

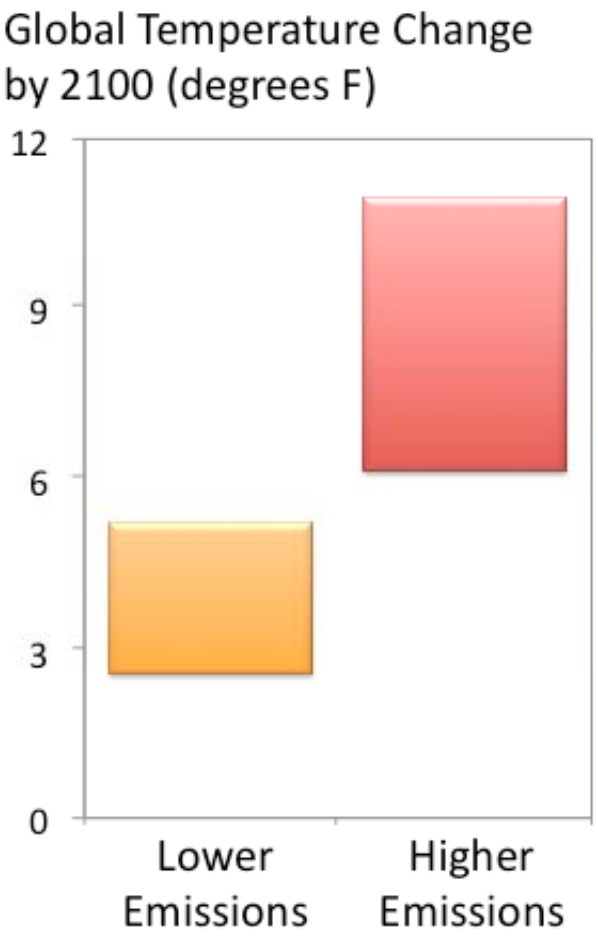
Hurricane power and ocean temperature

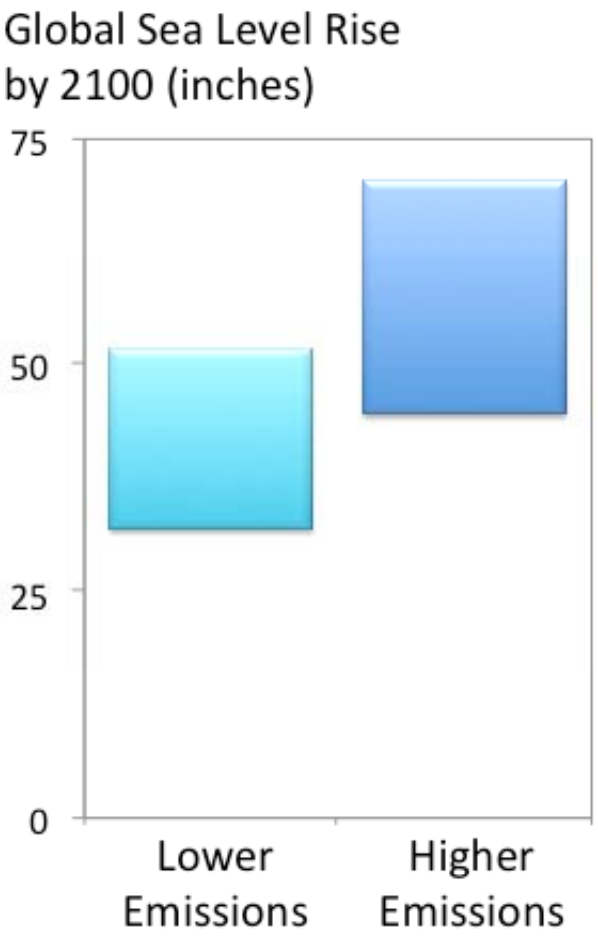


It's not so simple

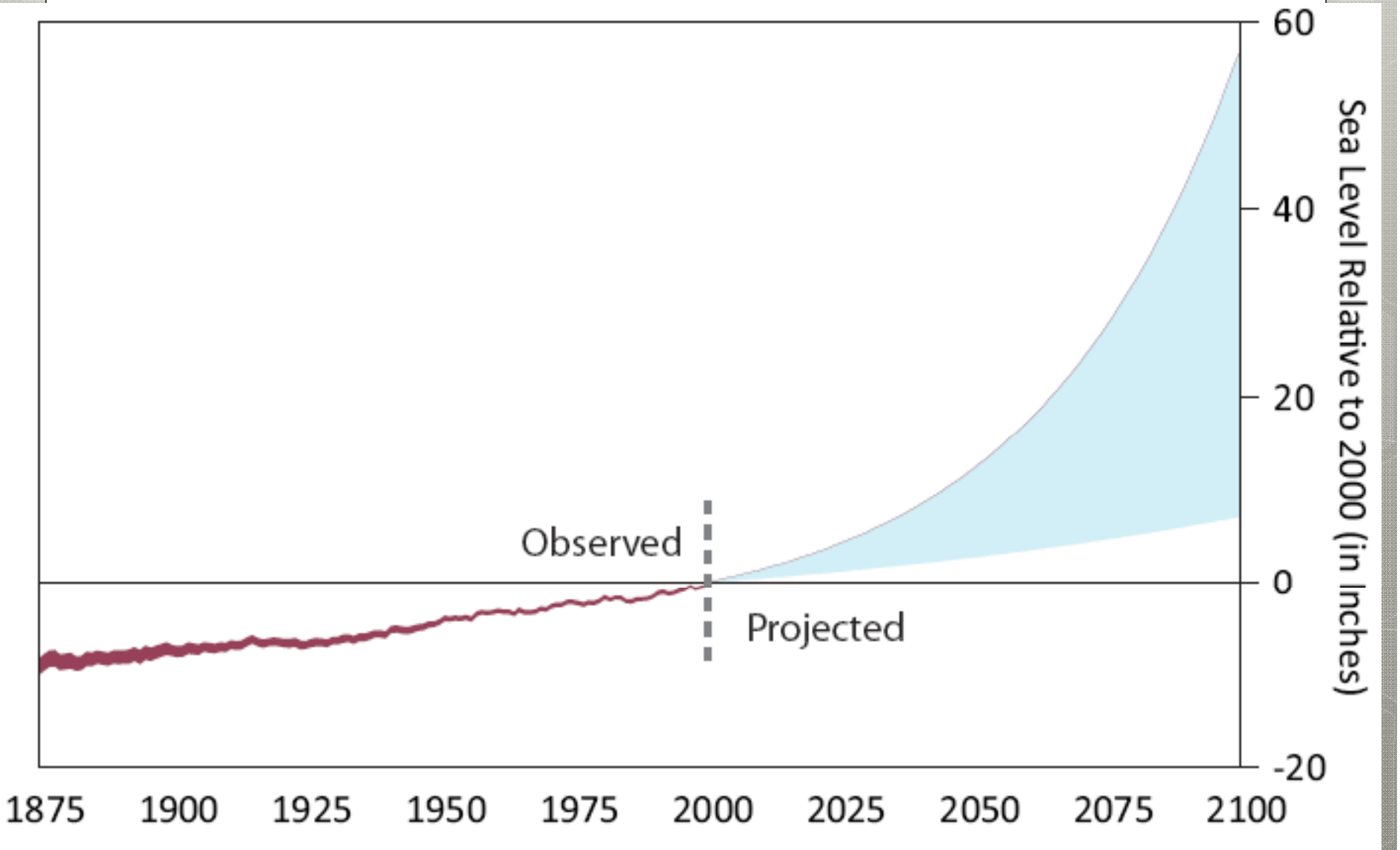
Mechanism	Likely change	Result
Ocean surface temperatures	Getting warmer	Longer season More powerful storms Greater number of storms
El Niño	More frequent	Suppresses hurricane formation
Atlantic Meridional Mode	Unsure	Alters location of hurricane formation; affects landfall frequency
Vertical wind shear	Decreasing	Conditions suitable for hurricane formation
Latent heat (condensation)	Increasing with warmer Ts	More rainfall associated with any hurricane

Sea Level Rise





Rising sea level



WHAT CAN WE DO?

PART FIVE

Here's what we know

1. At the global scale, climate is changing

- The past no longer a reliable guide to the future
- Averages are shifting and extremes are shifting

2. Global change *will* affect the Caribbean

- We can't attribute any single event, season, or even unusual year to global-scale change
- Over climate (30+ year) timescales, we do see changes consistent with the bigger picture

Here's what we can do

1. Conserve what we have

- Climate is only one of many stressors
- There are many reasons for conservation and wise allocation of already limited resources

2. Prepare for future change

- Smart planning can reduce our vulnerability to uncertainty, variability, and change
- Building resilient systems improves our ability to cope with many types of change, not just climate

Smart planning in Chicago

14 out of 18 city depts. identified temperature or precipitation-sensitive thresholds.

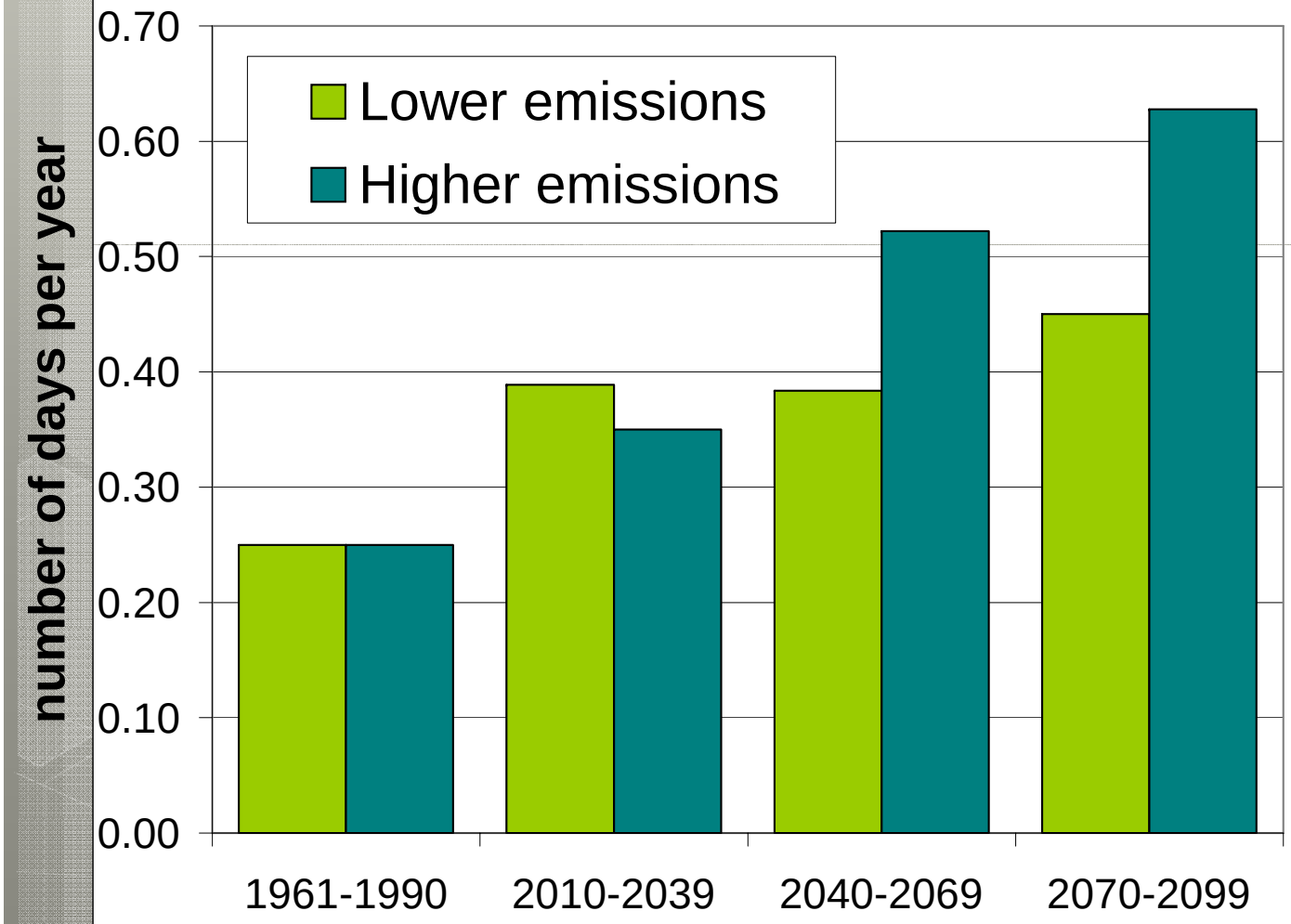
These included:

Chicago Transit Authority

Dept. of Transportation

Dept. of Emergency Response

Chicago: change in heavy rain events

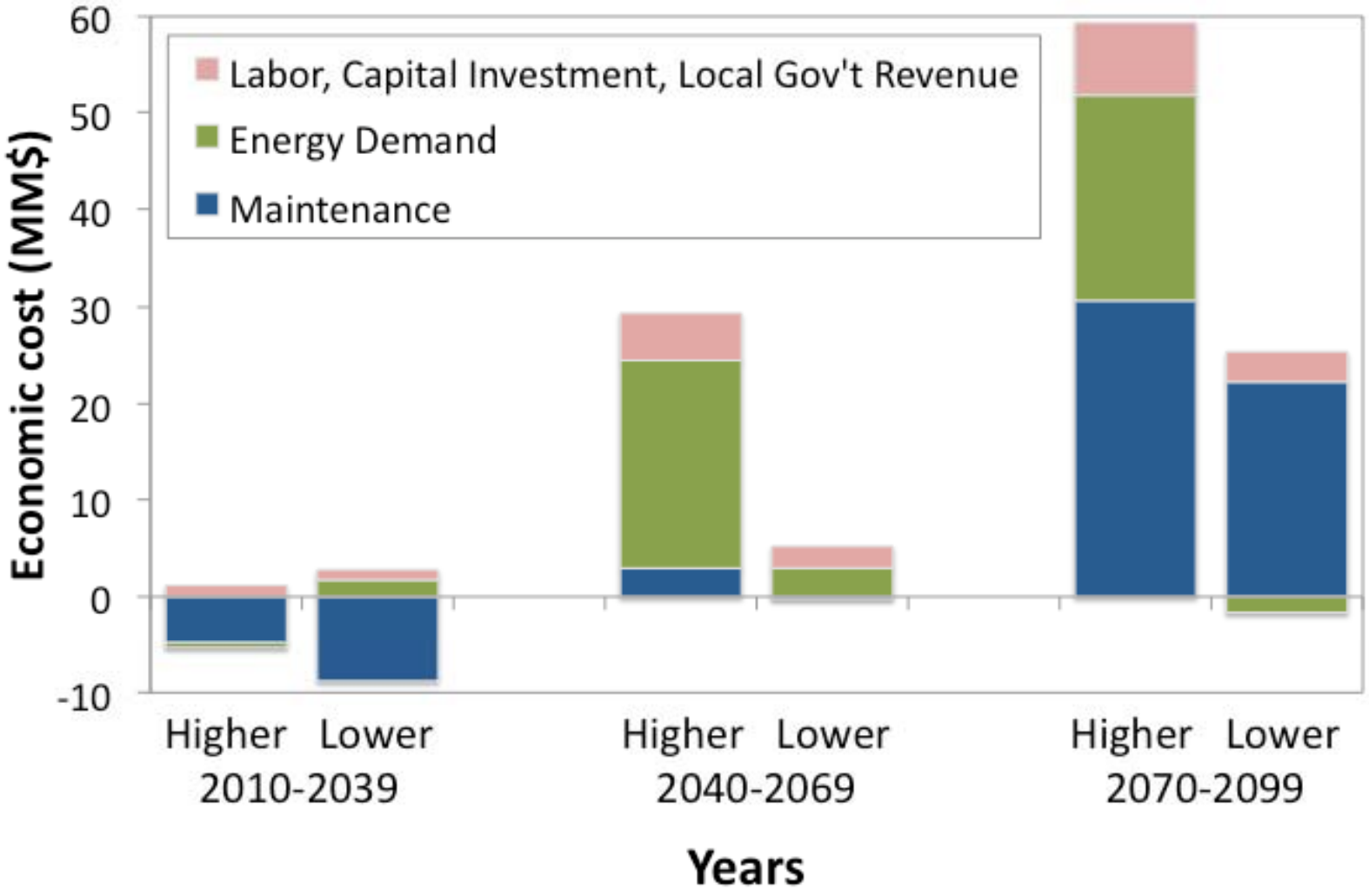


2.5” in 24hrs

Approximate threshold for combined sewer overflow into Lake Michigan

Leads to beach closings

Chicago: Infrastructure costs of climate



Prepare for what we can't avoid

Conserve the resources we have

Protect ourselves from what we can

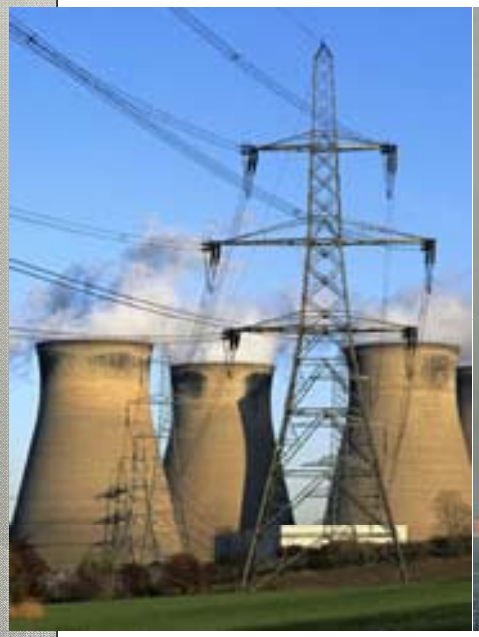
Reduce our own impact

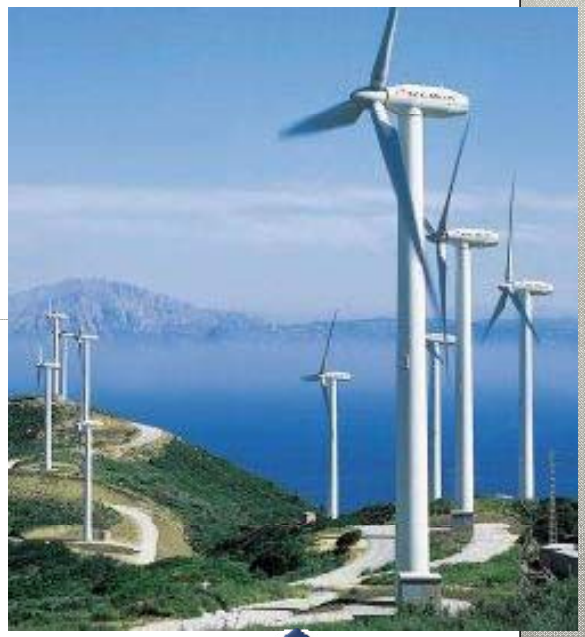
stop using this

start using this

Each US household replacing 1 light bulb
= taking 1,000,000 cars off the road (+$30 savings per bulb)

Support fundamental change





stop using this

start using this

Renewable energy gives us clean air and water, and home-grown energy sources that will never run out. So, why not?

IF EVEN TEXAS CAN DO IT…ANYONE CAN

THE END