# Important Climate Science Questions

1. Is Earth's climate changing?
2. If so, what is causing the changes?
3. Will the climate change during the 21st century (and beyond)?

## A Synthesis of Observations, Theory and Numerical Modeling

Gabriel Vecchi, with helpful input from Keith Dixon

# Science does not dictate action

Basic greenhouse physics

$CO_2$ increase anthropogenic

Earth is warming

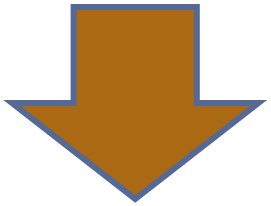
Warming is anthropogenic

Future climate change

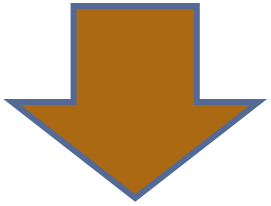
Impacts of future climate change

More certain

Less certain



## Values & Constraints



## Action

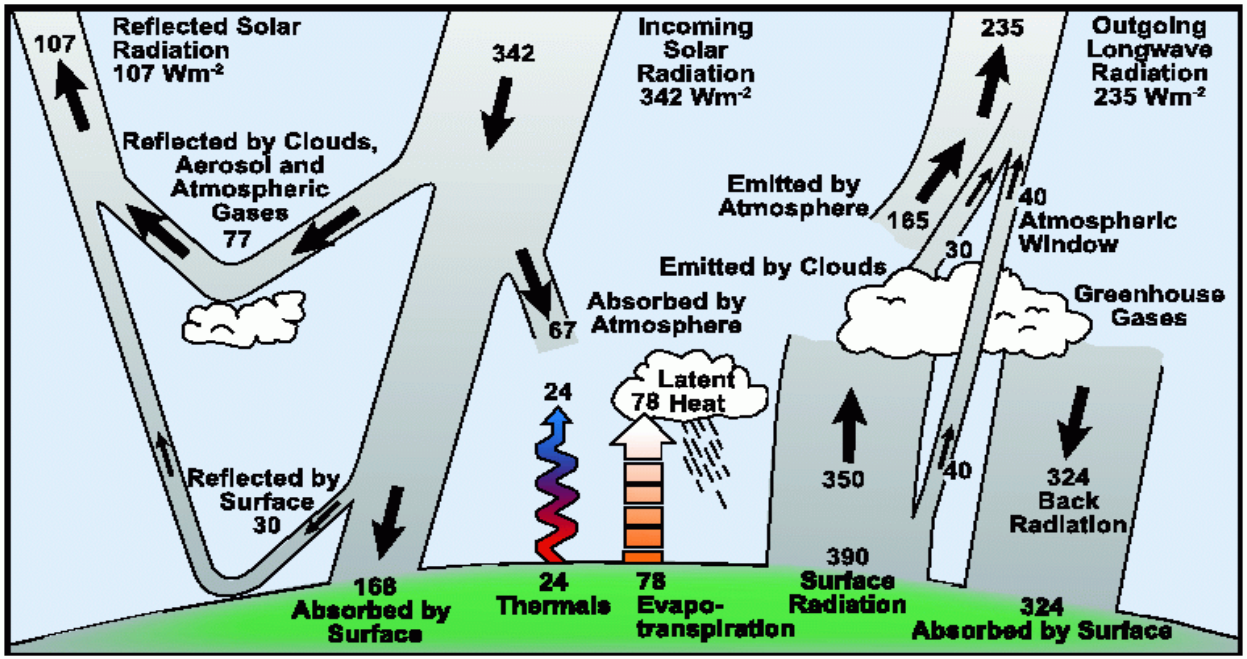
# Weather vs. Climate

- "climate is what you expect, weather is what you get." Lorenz (1965?)

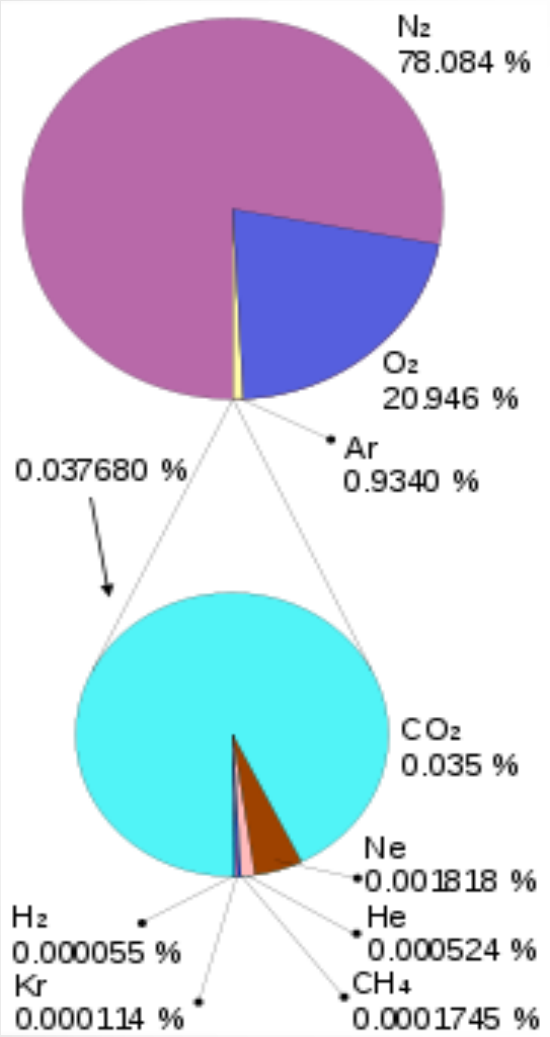
- Weather is the state of the atmosphere at a given time/place
  - Not predictable more than 3-5 days out
  - "Today is cooler than the day before yesterday"

- Climate is the statistics of weather:
  - Average, variability, extremes, etc.
  - "Summer is hotter than winter"
  - Aspects potentially predictable if you know forcing many years/centuries in advance.

# Earth's energy balance is the key to global climate changes




IPCC



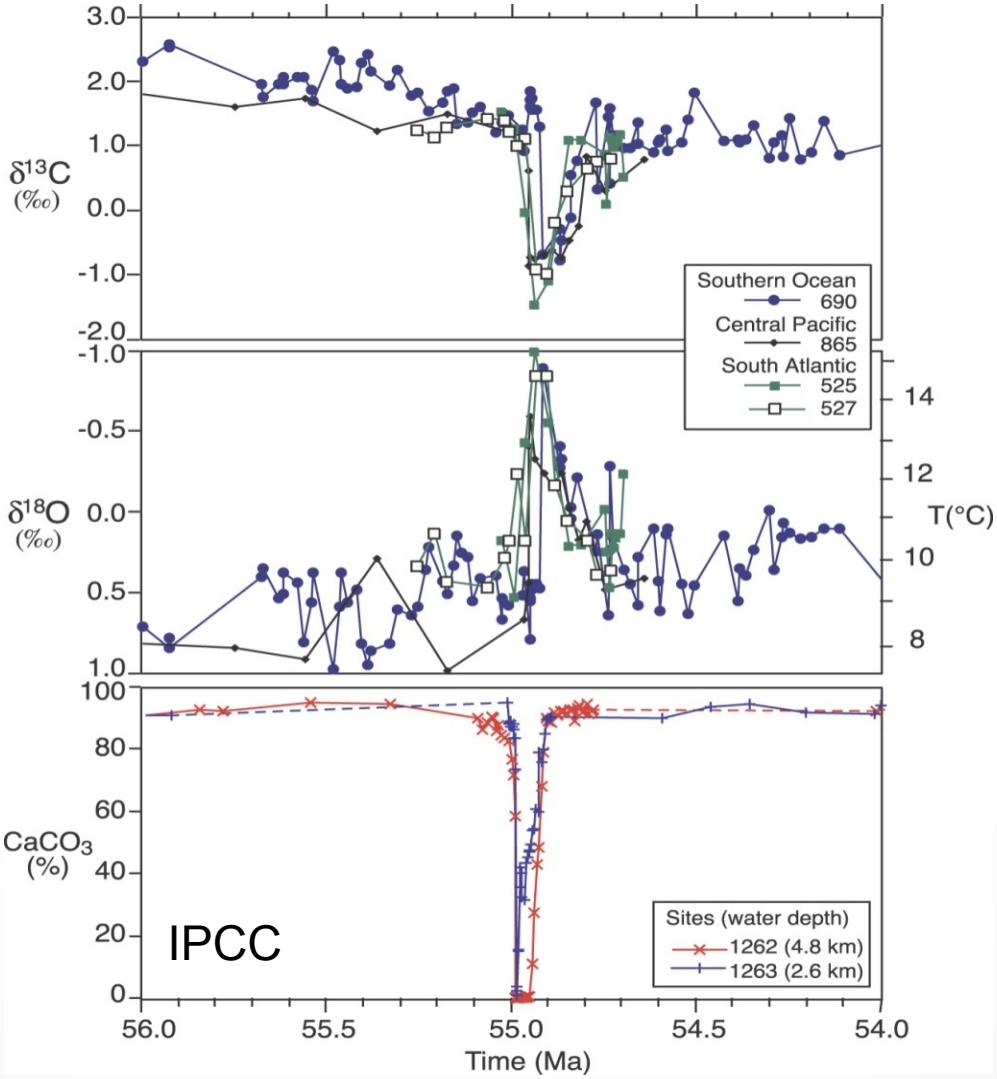

Wikipedia

1) Only a small minority of atmospheric molecules contribute to the greenhouse effect

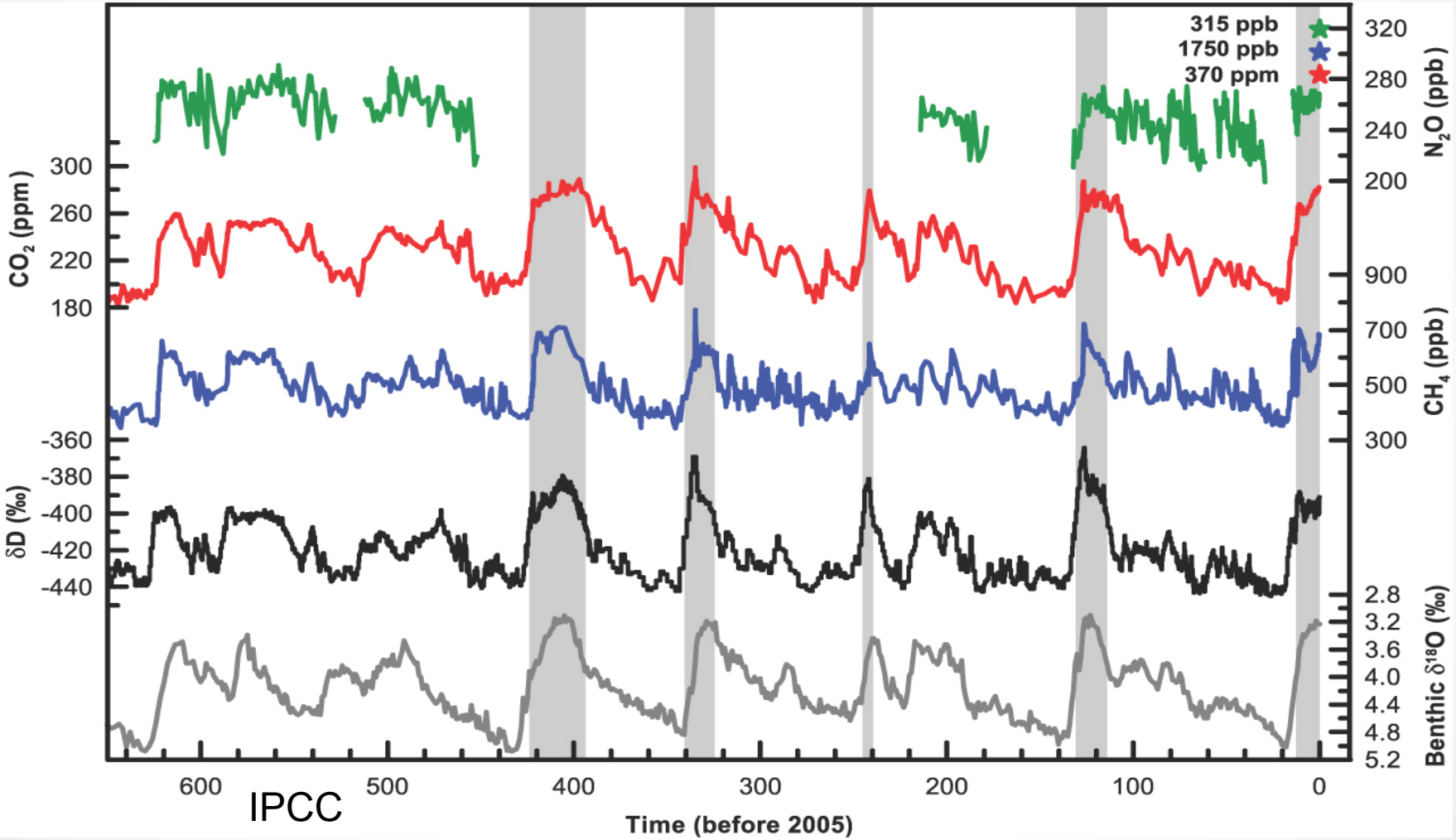
2) Water vapor, the most important greenhouse gas, is present in an amount determined by temperature (it acts as a positive feedback)

3) The change in greenhouse effect from changing a greenhouse gas concentration depends on the fractional change

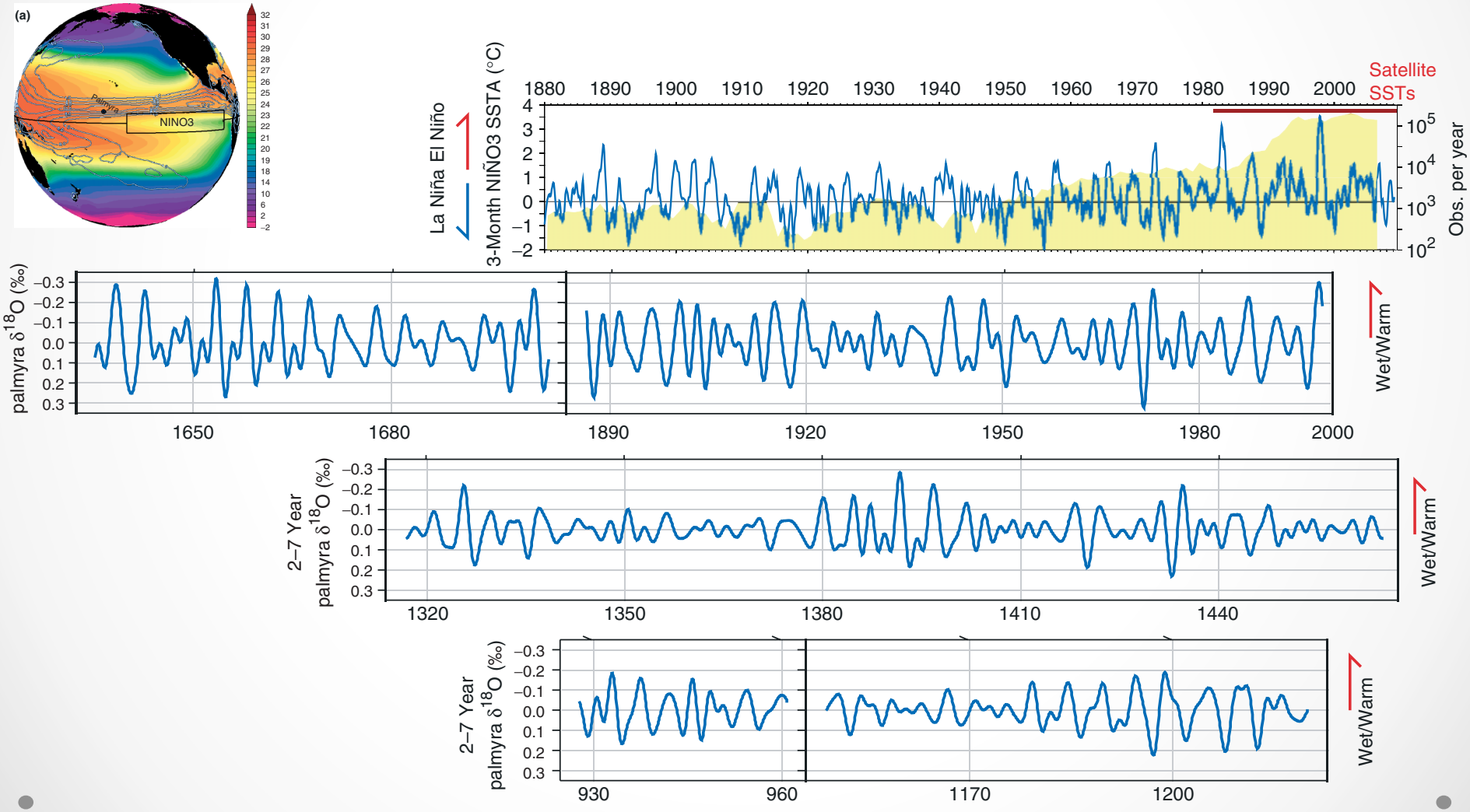
# Paleocene-Eocene Warm Event: climate has changed in past, due to changes in earth's energy balance



# Ice Age Cycles: climate has changed in past, due to changes in earth's energy balance



# El Niño: climate has changed in past, due to chaotic variations in climate system




*Vecchi and Wittenberg (2010, WIRES)*

## 1. Is Earth's climate changing?

# Looking Back:
## Past climate variability & change – an issue of Detection

### From the 2007 Intergovernmental Panel on Climate

### Change Report (WG1):

"Warming of the climate system is **unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

# 1. Is Earth's climate changing?

IPCC WGI Fourth Assessment Report

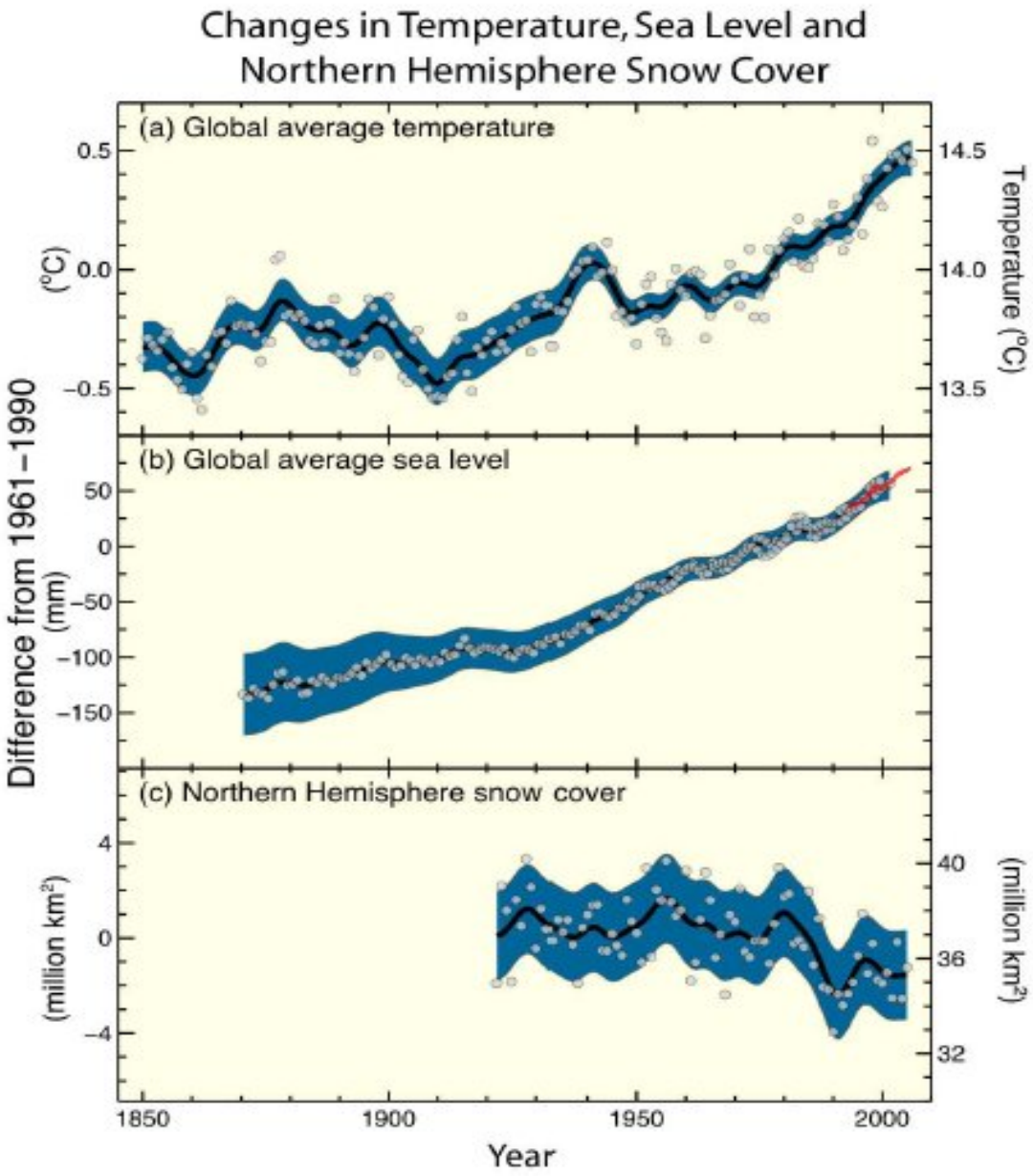
## Observational Evidence:

**Sfc Air Temp. Warming**

**Global Avg. Sea Level Rising**

**N.H. Snow Cover Decreasing**

Significance of trends determined from obs & modeled internal variability



# 2. What is causing the changes?

## A question of Attribution:

### From the 2007 Intergovernmental Panel on Climate Change Report (WG1):

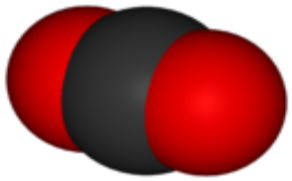
**"Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely** due to the observed increase in anthropogenic greenhouse gas concentrations."**

*very likely = 90-95% certainty

# 2. What is causing the changes?

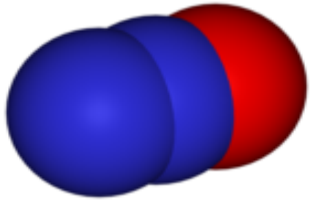
**Observational Evidence for Greenhouse Gas Increases:**

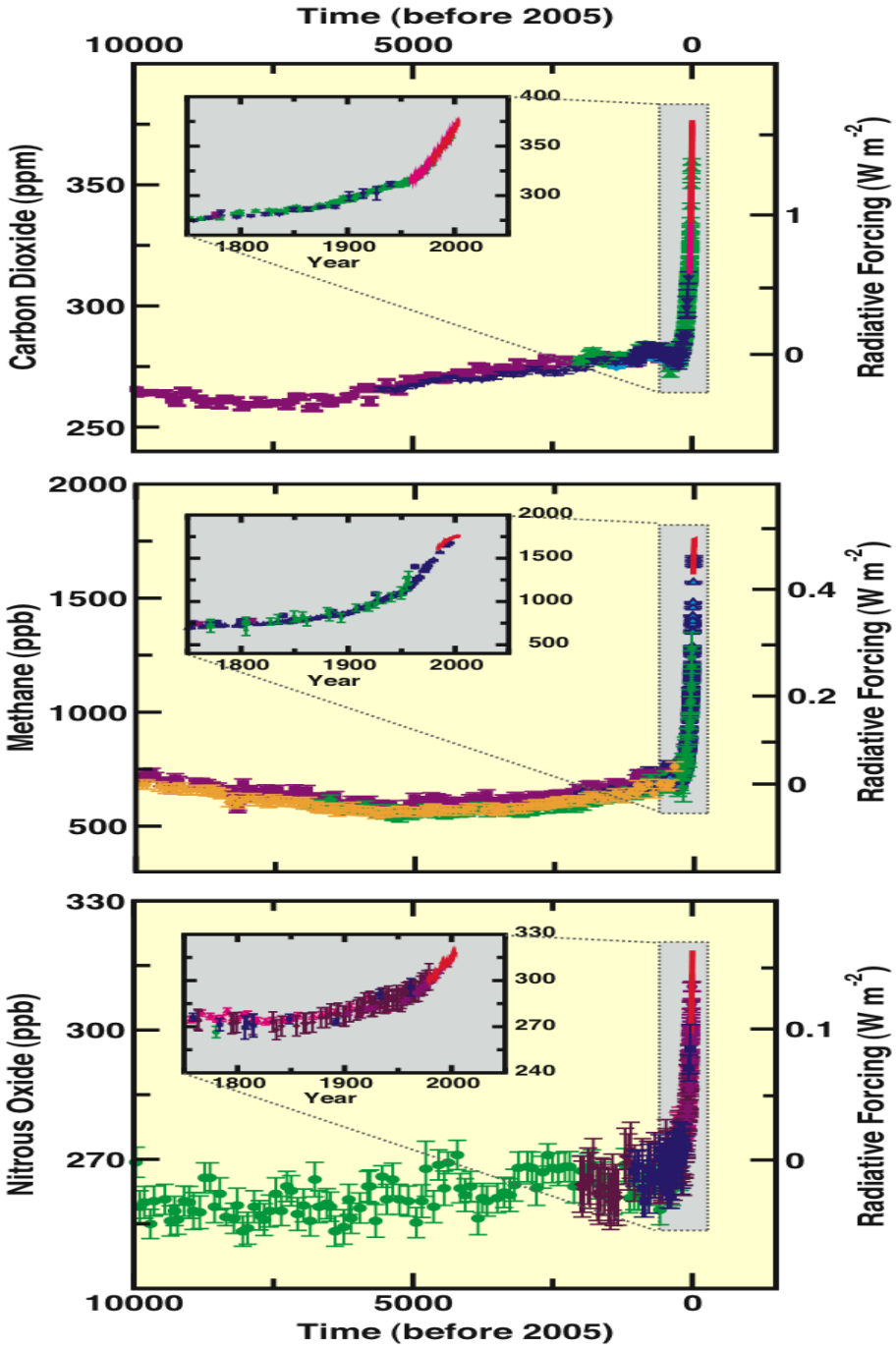
**Carbon Dioxide**

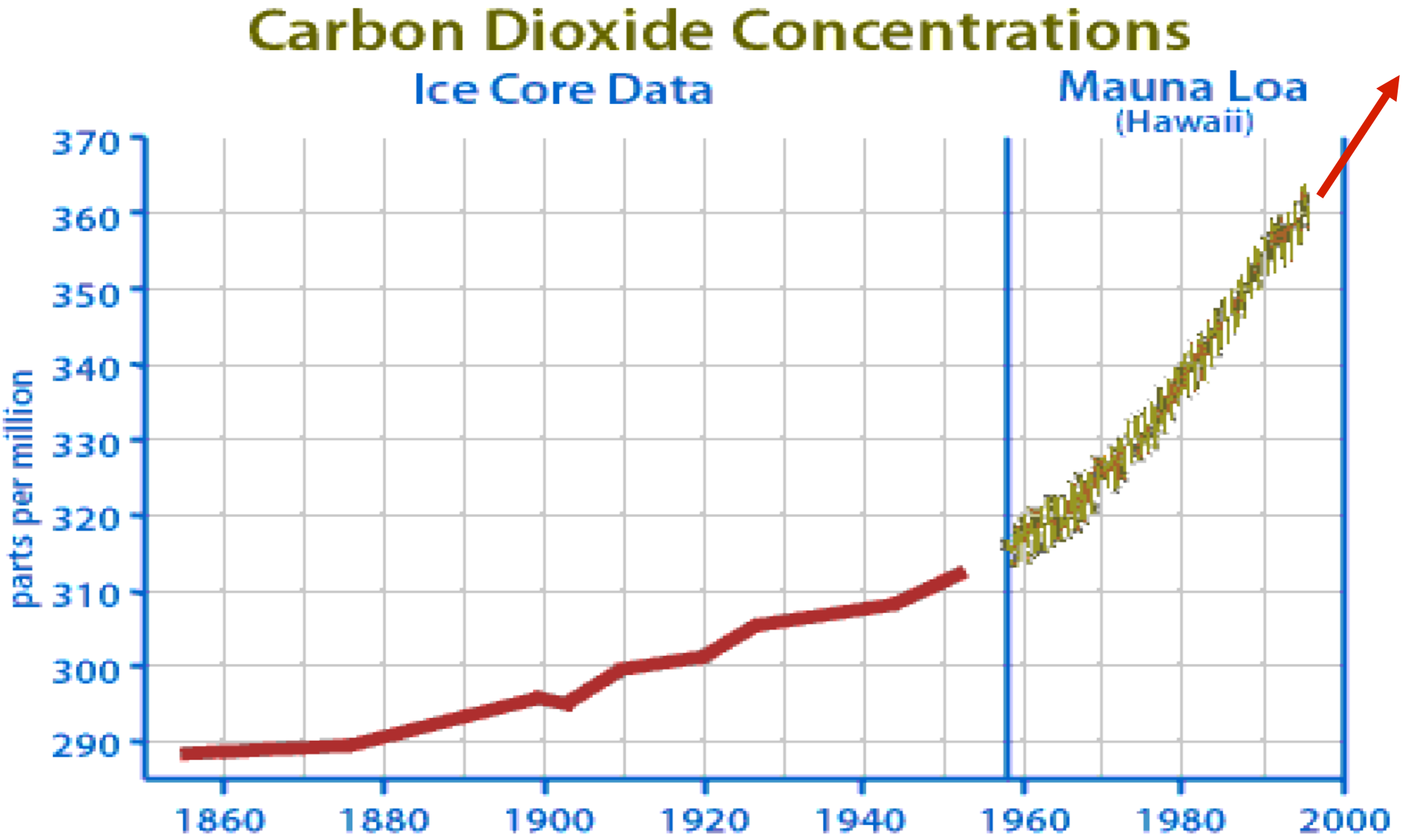


**Methane**

**Nitrous Oxide**

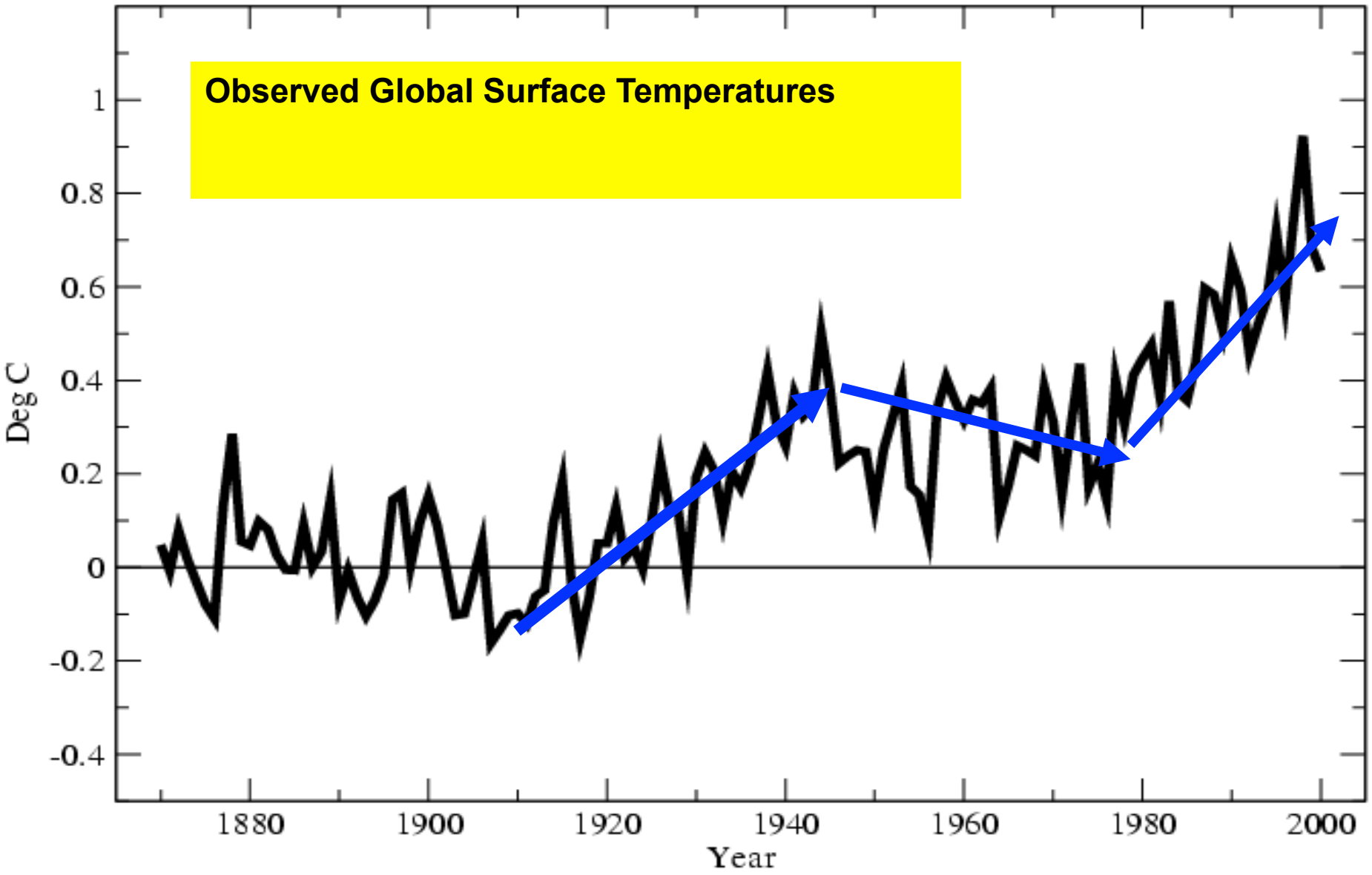





Carbon Dioxide Concentrations
Ice Core Data
Mauna Loa
(Hawaii)
parts per million
370
360
350
340
330
320
310
300
290
1860
1880
1900
1920
1940
1960
1980
2000

# 2. What is causing the changes?

## Variations of the Earth's Surface Temperature



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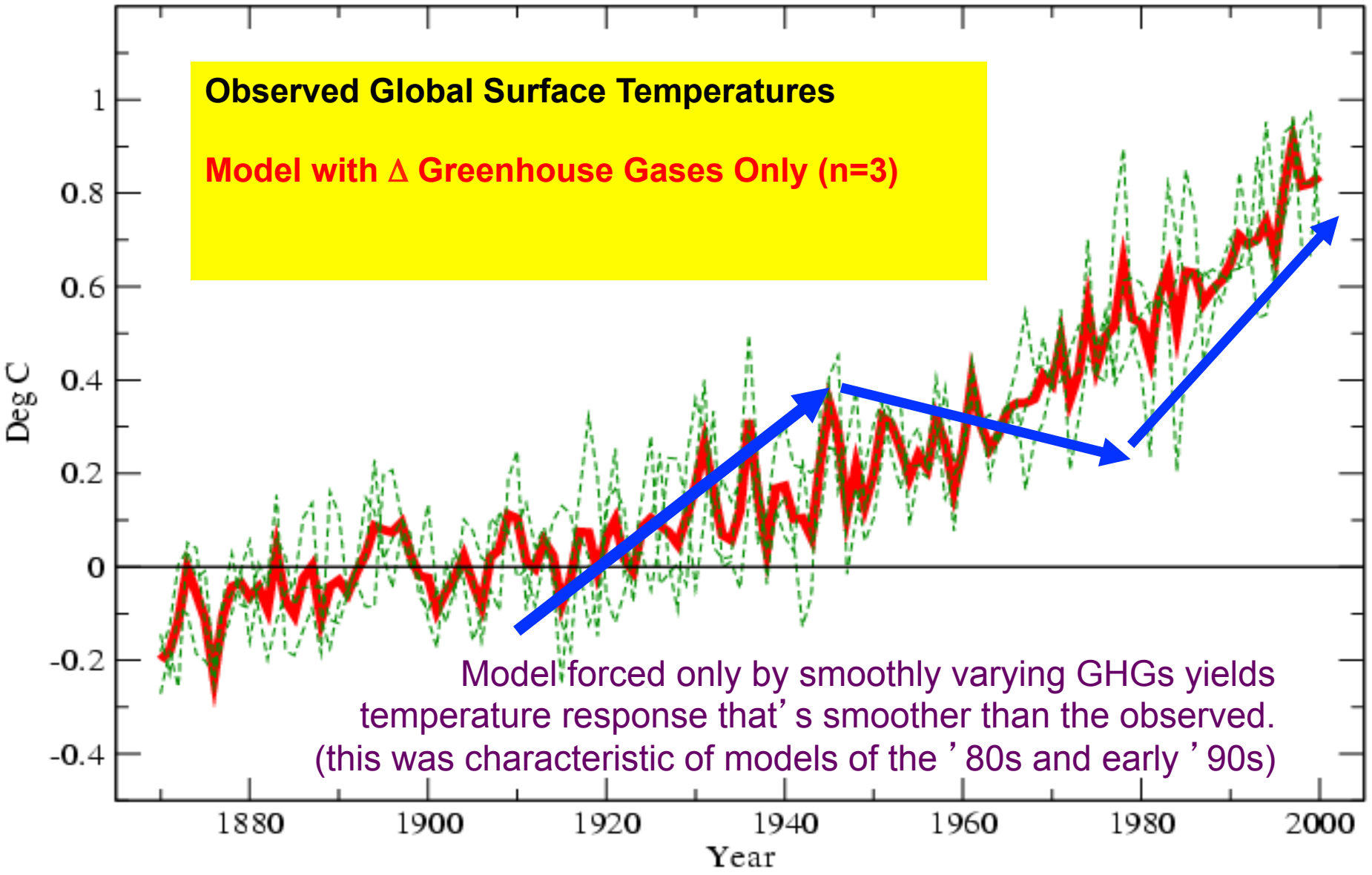

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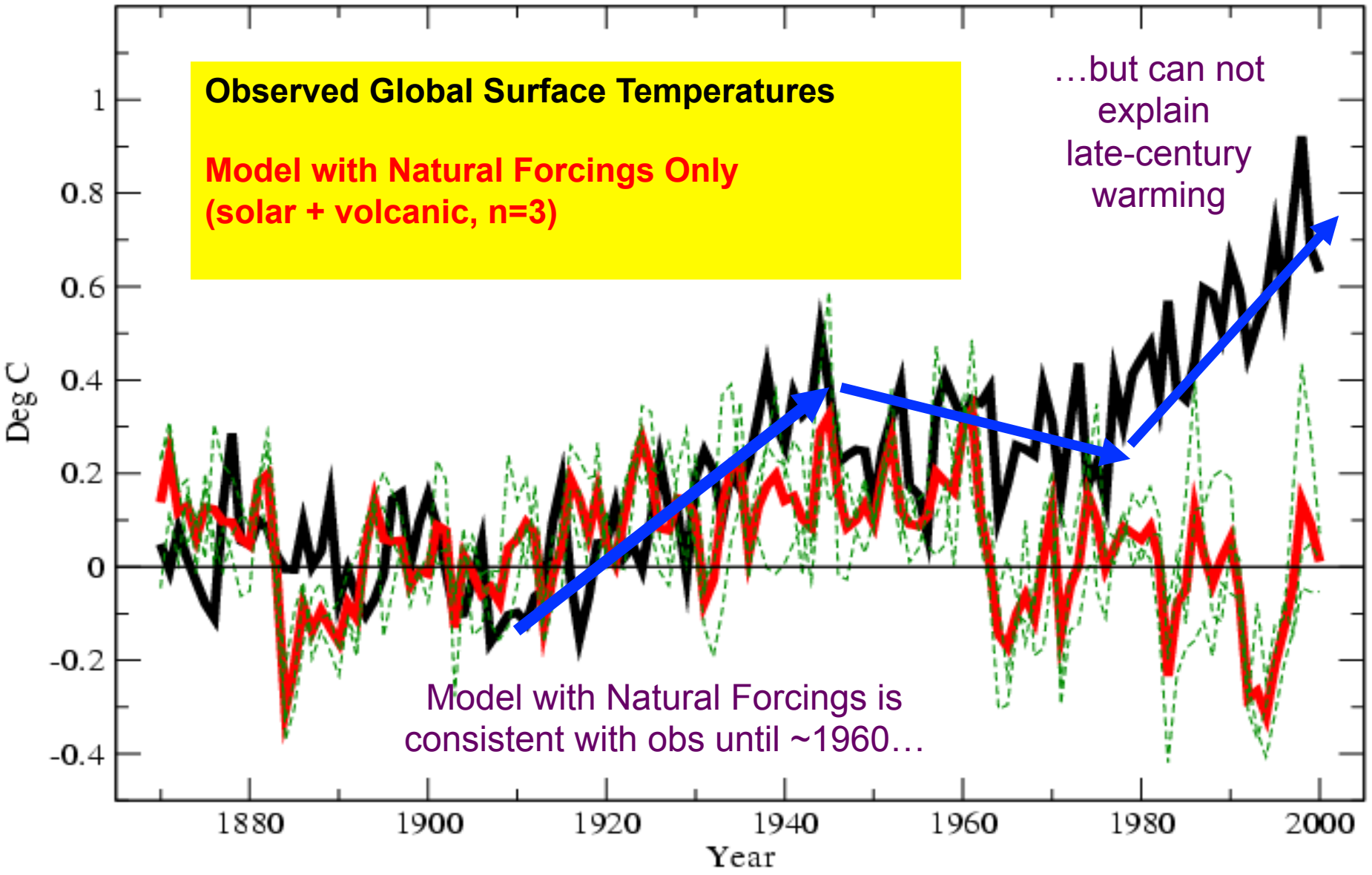

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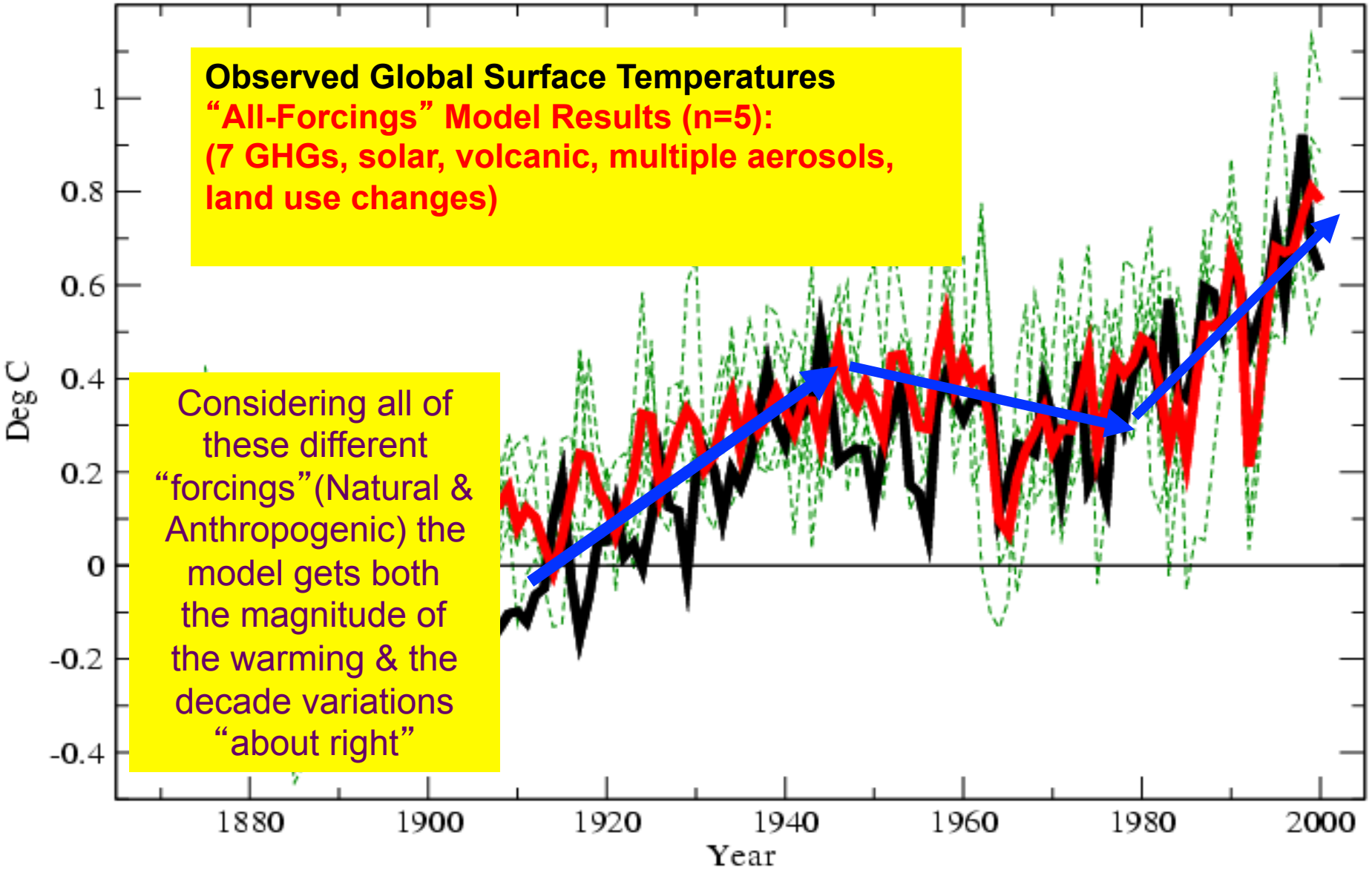


# Uncertainties In Climate Change Projections

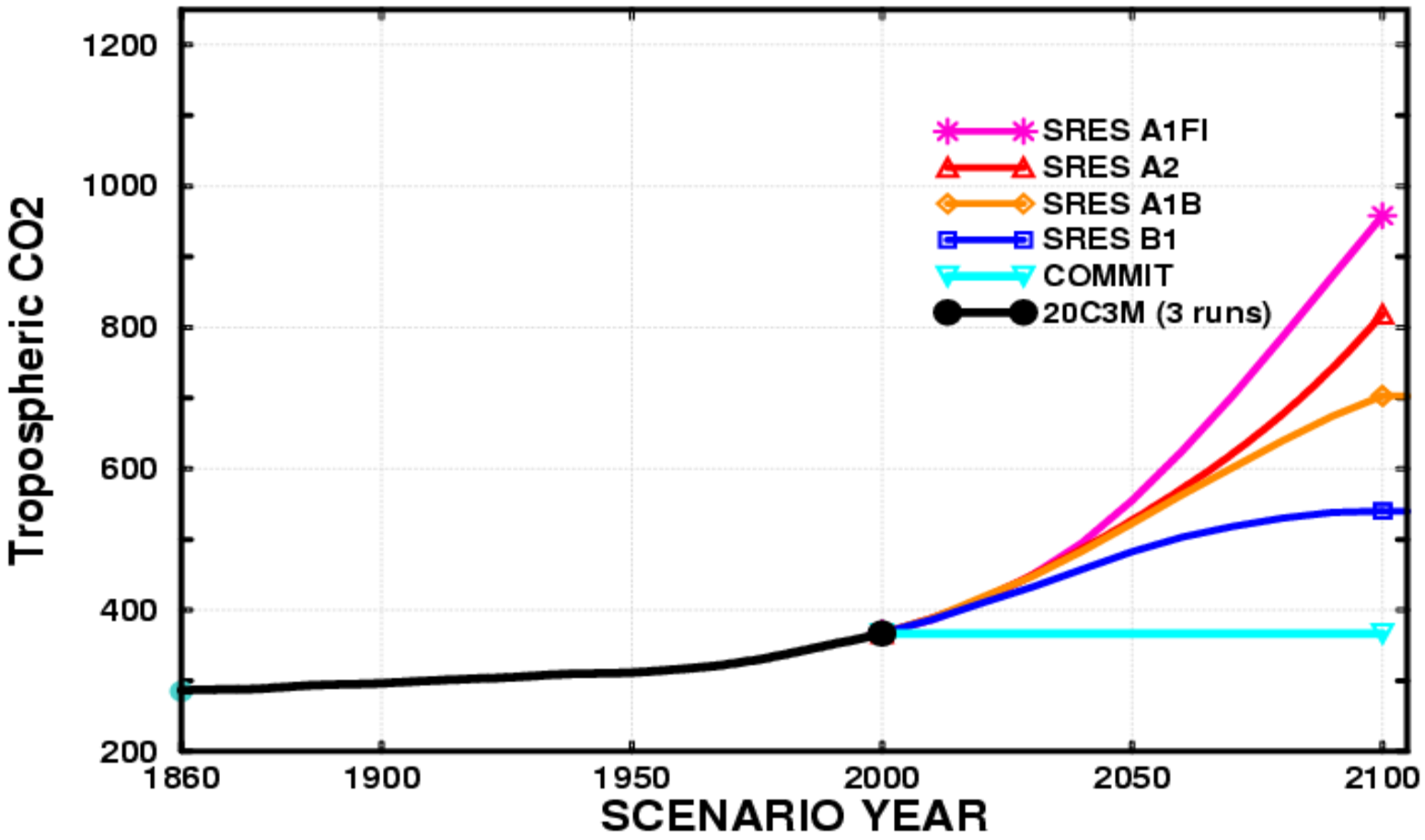
**Three broad types of uncertainties:**

1) **What will be the future concentrations of greenhouse gases in the atmosphere?**
*(depends on population size, economic growth, energy use efficiency and development of alternative energy sources)*

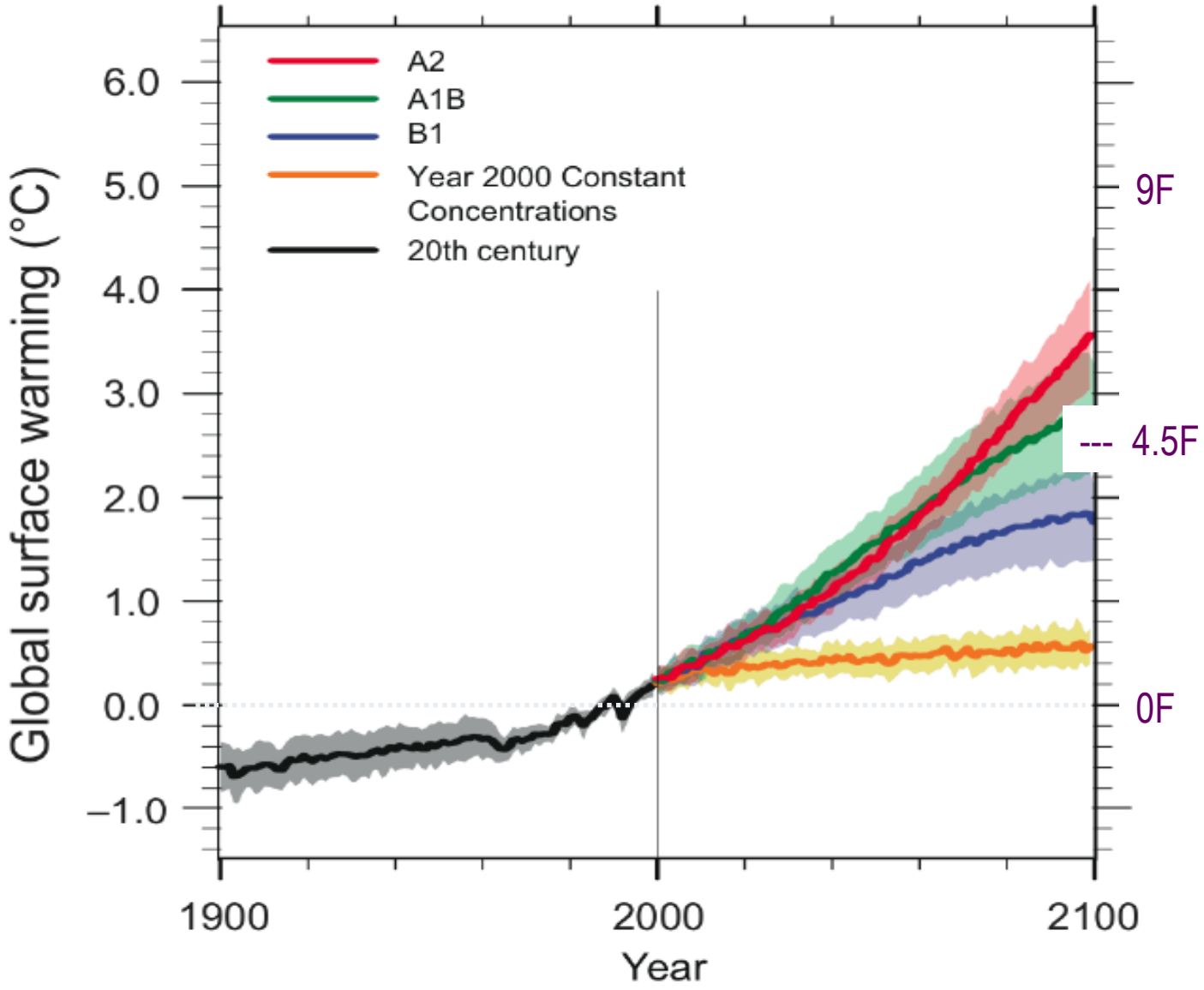
2) **How will the climate system respond to the changes in greenhouse gases?**
*(the computer models are incomplete & are not perfect)*

2) **What chaotic fluctuations of climate will there be?**
*(greenhouse response does not mean an end to weather)*

## GFDL CM2.X Experiments



# Multi-model Averages and Assessed Ranges for Surface Warming

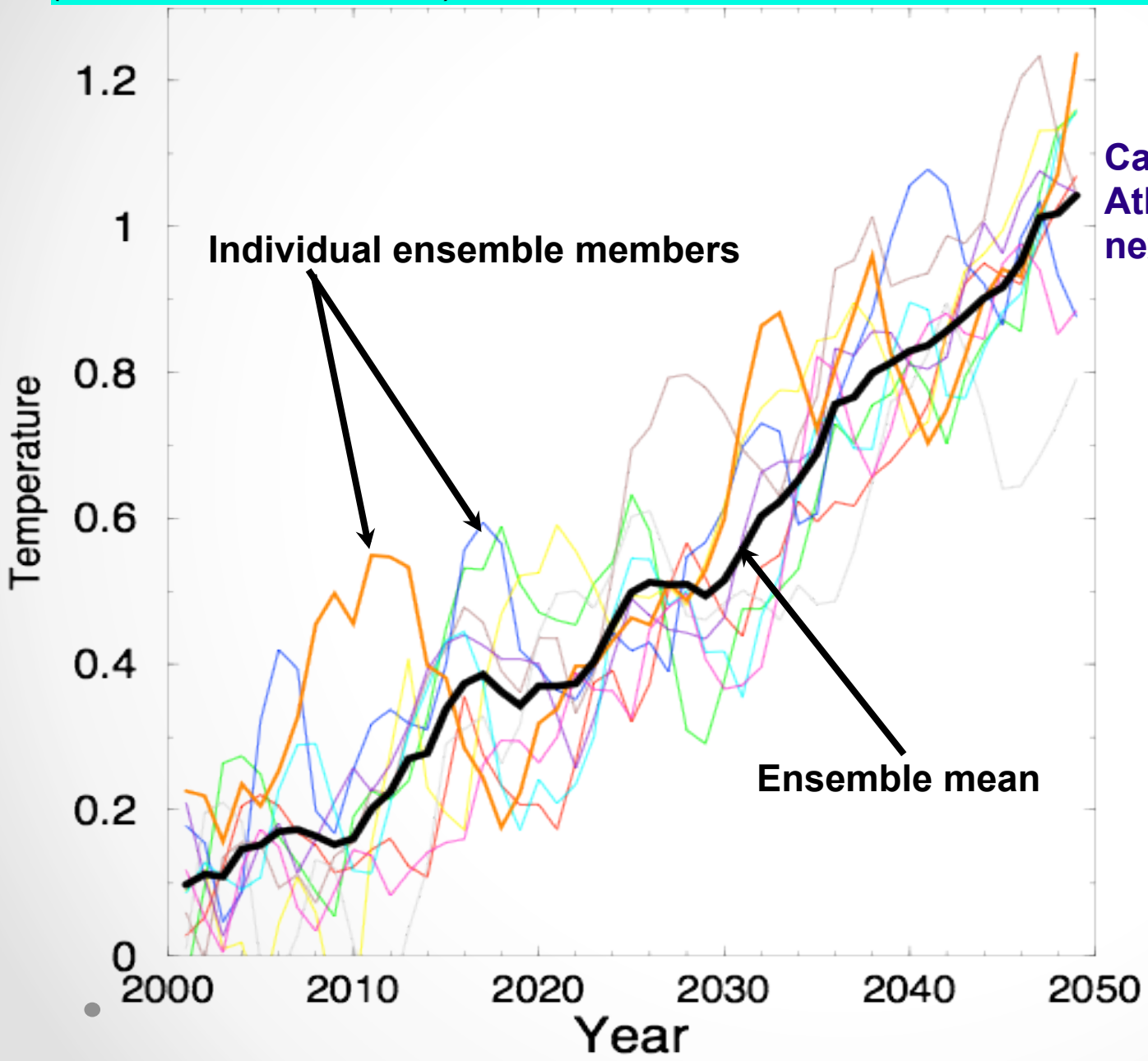



Model projections following 3 different "If…Then" 21st cent. emissions scenarios and the "Committed Climate Change" scenario.

Shaded areas show +/- 1 std. dev. of model runs.

# Simulated Atlantic Sea Surface Temperature

*(based on GFDL CM2.1)*




**Can we predict the trajectory of Atlantic temperatures over the next several decades?**

# Uncertainties In Climate Change Projections

Rules of thumb:

**The smaller the spatial scale or time scale, the greater the uncertainty.**

**The smaller the spatial scale, time scale or time horizon, the larger the role for chaotic climate variability.**

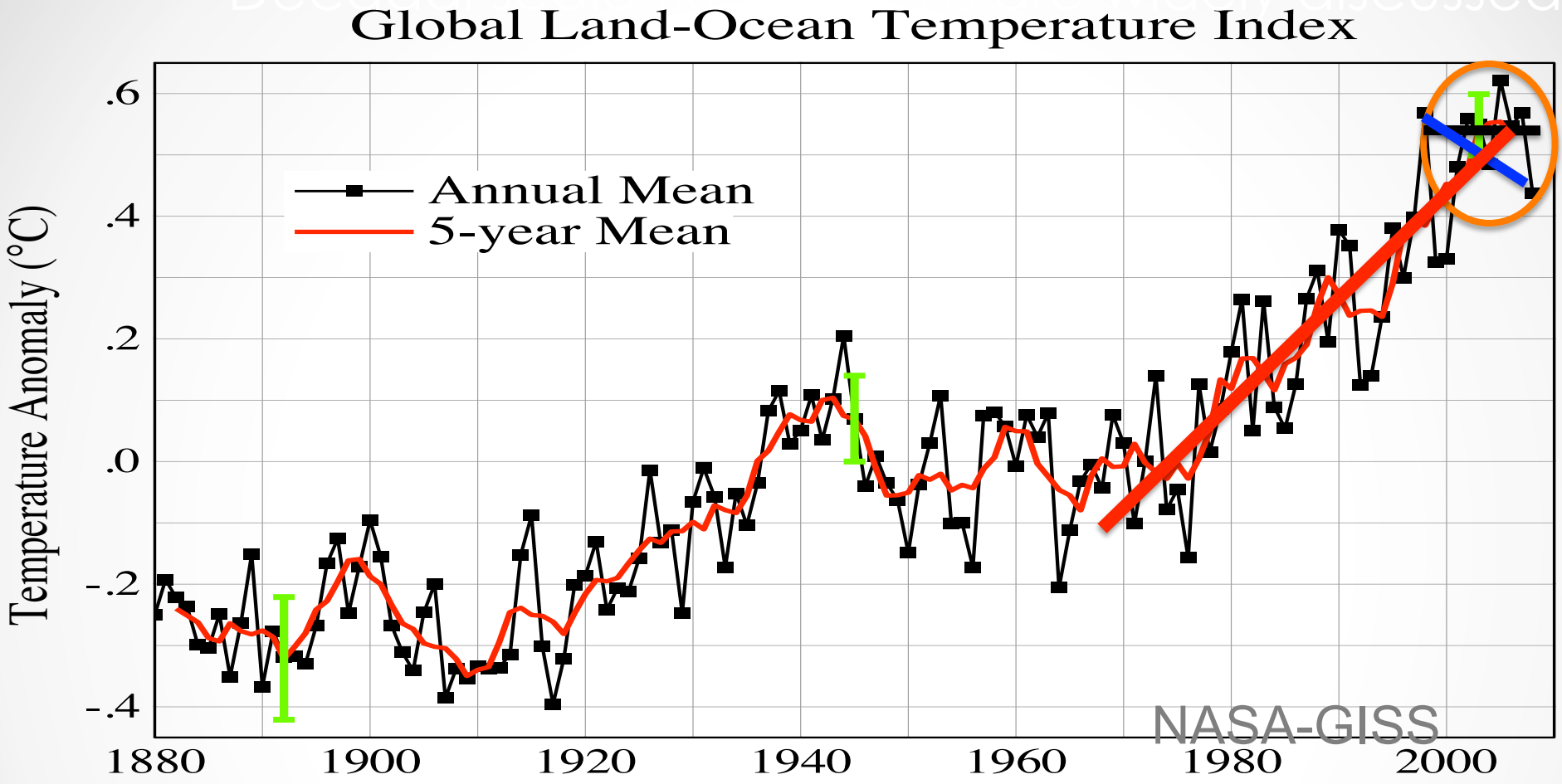
**The more complex or extreme the phenomenon, the greater the uncertainty.**

# SUMMARY

*The strong scientific consensus is that we are seeing more signs that human caused climate change is real and that change will become more rapid in the coming century.*

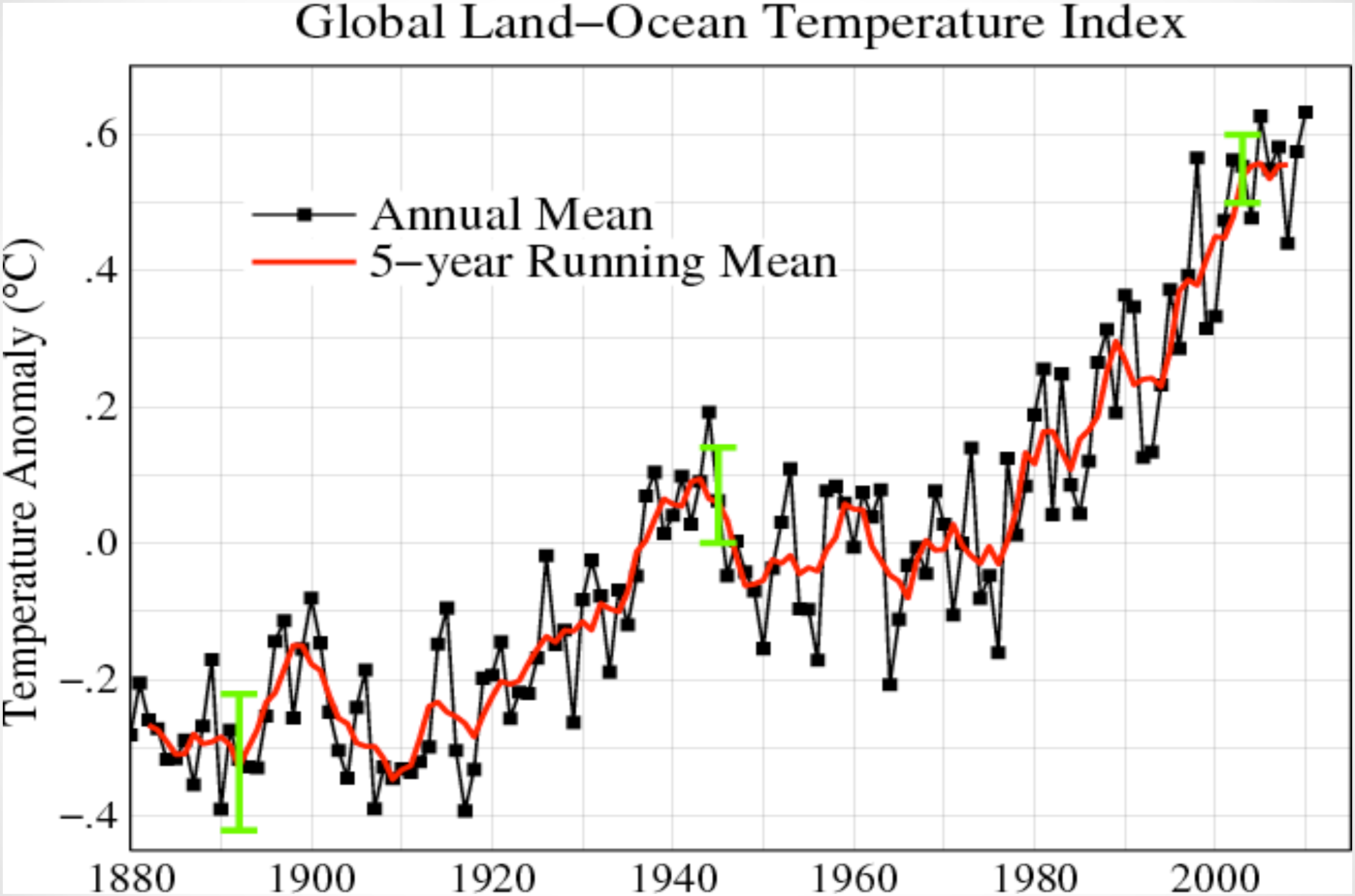
*Though we understand aspects of the large-scale response of the climate system, the implications for other (more regional or complex) phenomena remain less clear.*

Decadal scale fluctuations are widely discussed …




"***If you're 29, there has been no global warming for your entire adult life. If you're graduating high school, there has been no global warming since you entered first grade. There has been no global warming this century. None.***"

Mark Steyn, National Review online, July 4, 2009,as quoted by syndicated columnist George Will on July 23, 2009 in the Washington Post

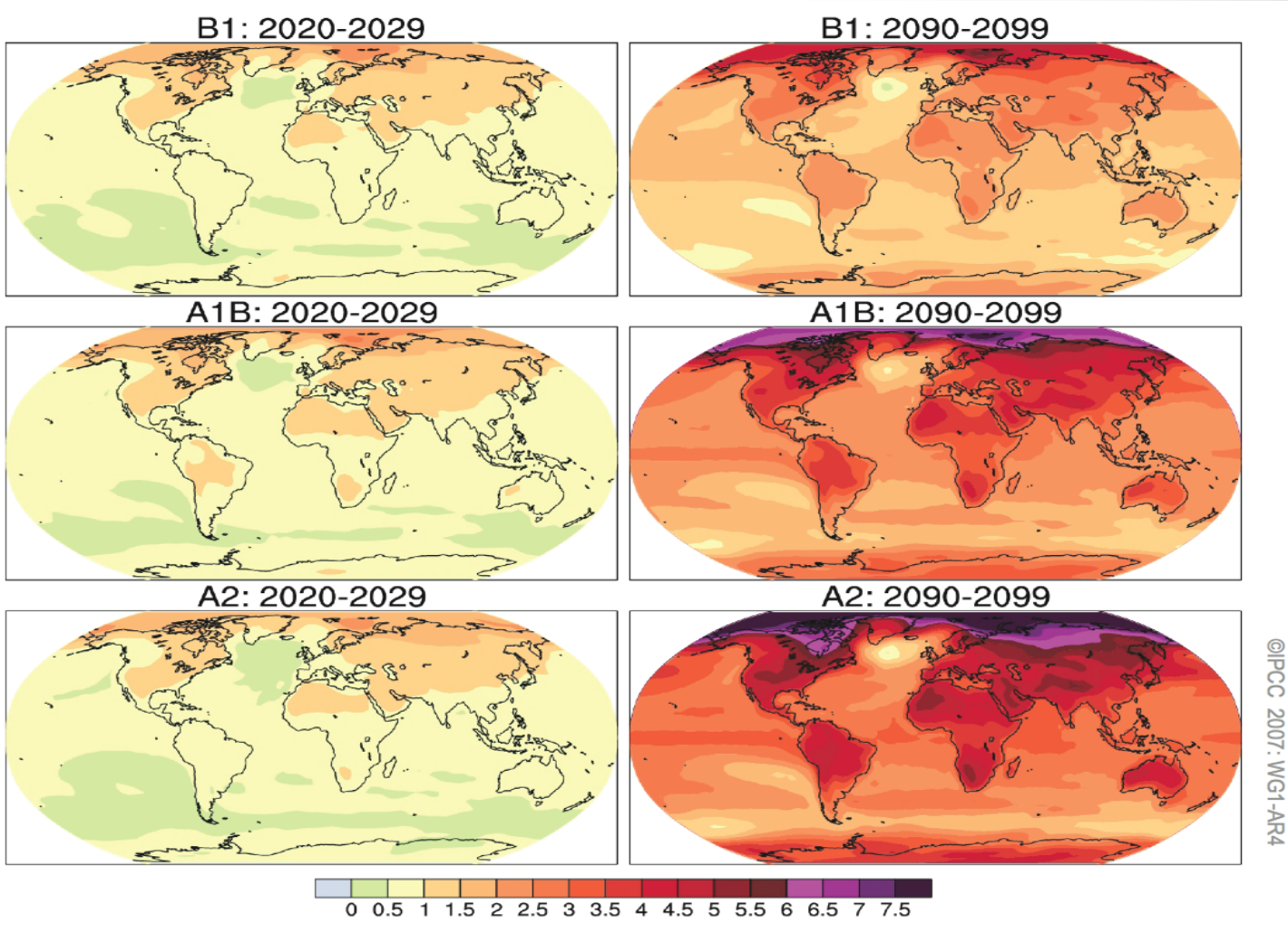

Global Land–Ocean Temperature Index
Temperature Anomaly (°C)
.6
.4
.2
.0
–.2
–.4
Annual Mean
5–year Running Mean
1880
1900
1920
1940
1960
1980
2000

NASA-GISS

# BINKY SLIDES

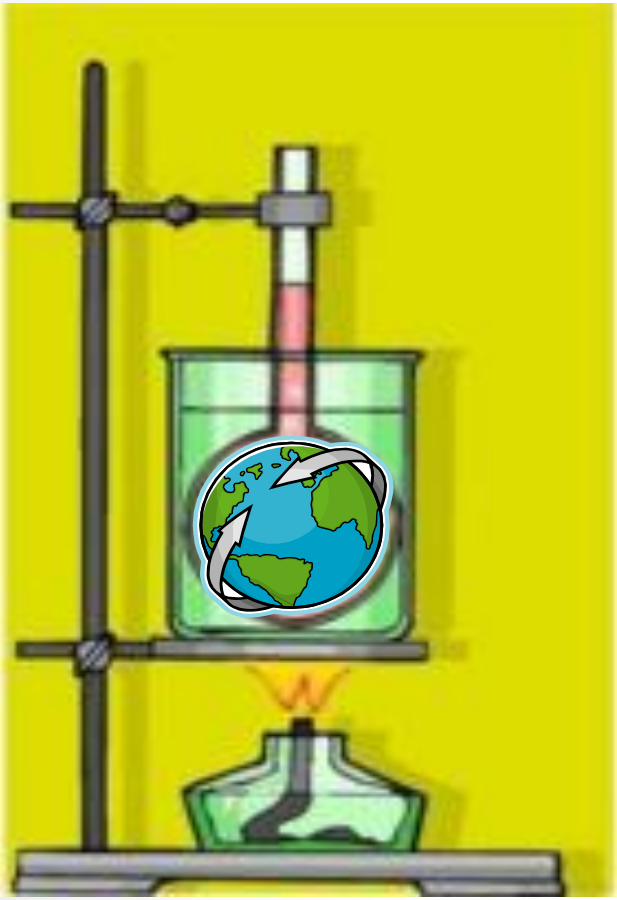
# Projections of Future Changes in Climate

Projected warming in 21st century expected to be greatest over land and at most high northern latitudes and least over the Southern Ocean and parts of the North Atlantic Ocean



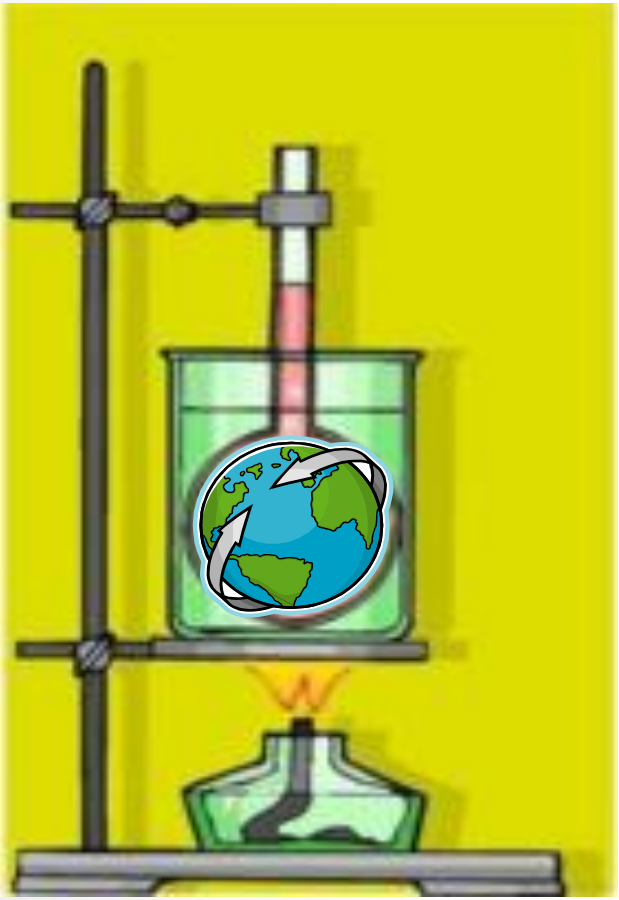

Source: IPCC 4th Assessment Report. Used with permission.

# What is a State-of-the-Art Global Climate Model?



**Unfortunately, we don't have a twin planet earth that we can use to perform laboratory experiments.**

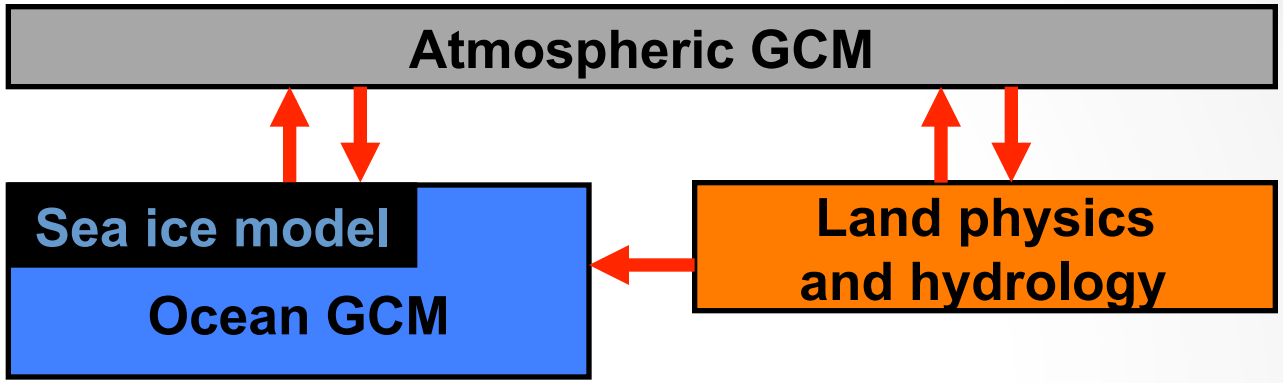
# What is a State-of-the-Art Global Climate Model?



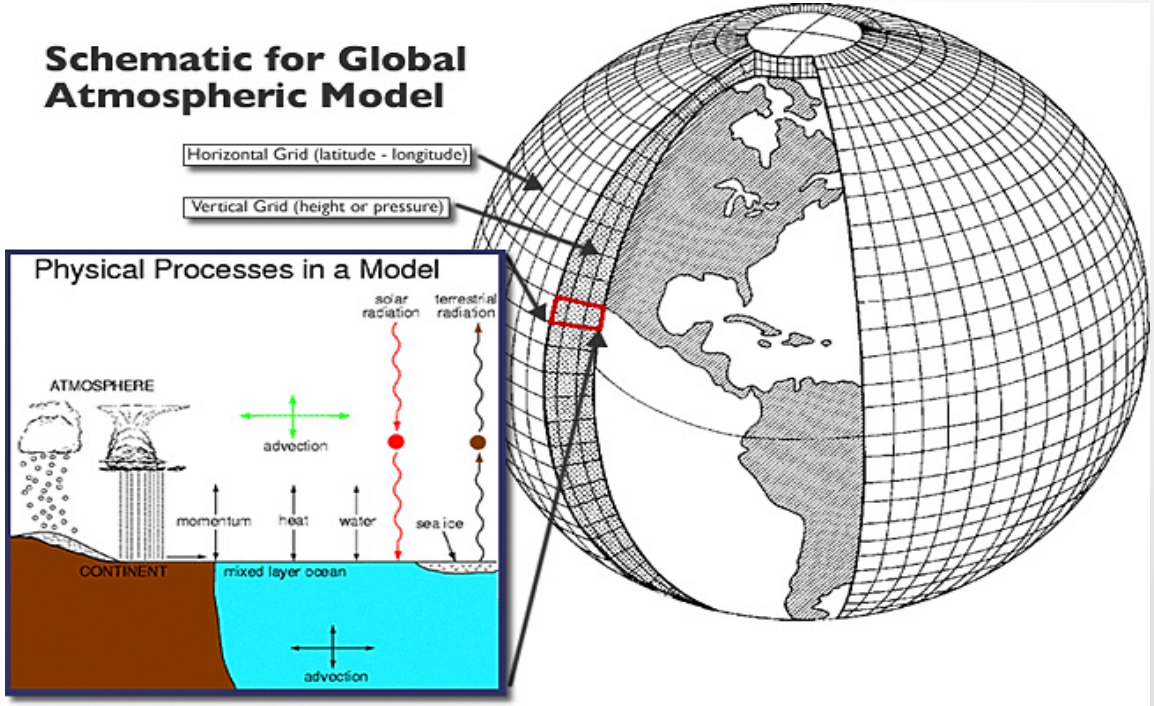
- At GFDL, the computer is our lab.
- The computer model is our research tool.

# What is a State-of-the-Art Global Climate Model?

The four physical climate components




At GFDL, our newest model has more than 2,000,000 atmospheric grid cells and over ten million ocean grids cells. And there's thousands more for the land and sea ice model components.



# The Climate Model Knowledge Cycle

THEORY

OBSERVATIONS

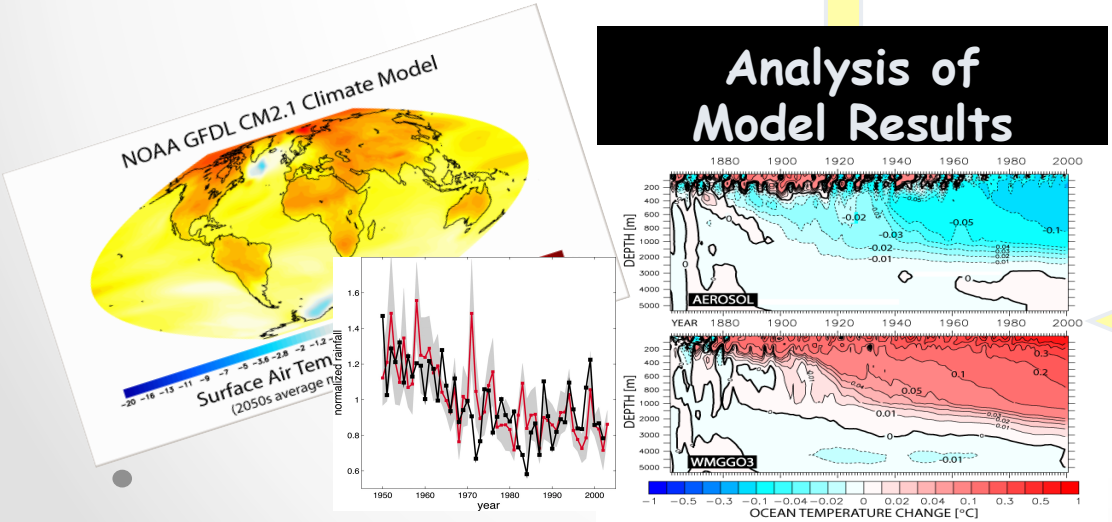
Knowledge & Understanding

Model Development

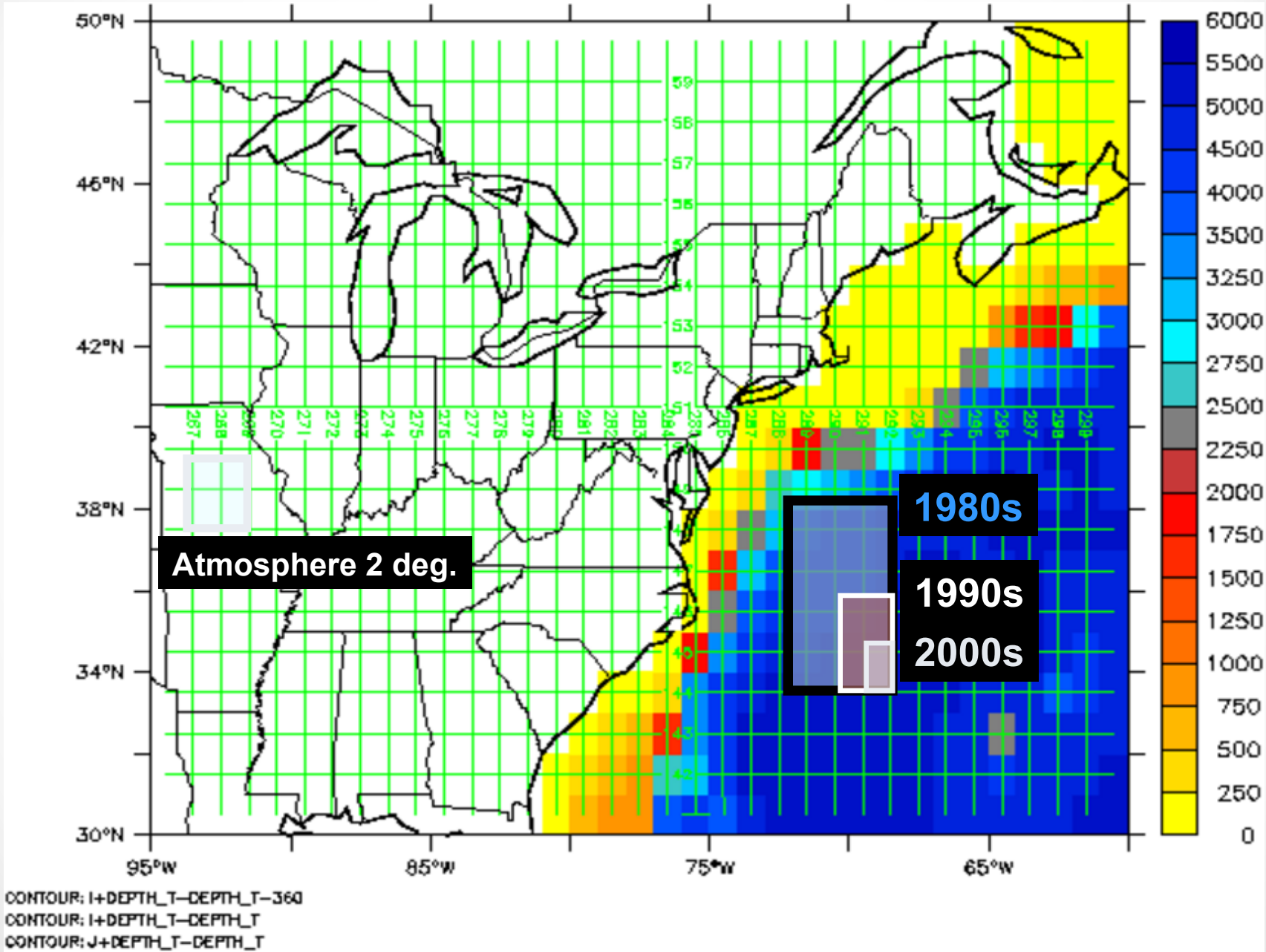
```
if (diagts .and. eots) then
  do 1500 m=1,nt
    do 1490 k=1,km
      fx = cst(j)*dyt(j)*dzt(k)/(c2dtts*dtxcel(k))
      do 1480 i=2,imtm1
        boxfx           = fx*dxt(i)*fm(i,k,jc)
        sddt            = (ta(i,k,m)-t(i,k,jc,nm,m))*boxfx
        svar            = (ta(i,k,m)**2-t(i,k,jc,nm,m)**2)
                          *boxfx
        n               = 0
        termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
        tvar(k,m,n)     = tvar(k,m,n)     + svar
        n     = nhreg*(mskvr(k)-1) + mskhr(i,j)
        if (n .gt. 0 .and. mskhr(i,j) .gt. 0) then
          termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
          tvar(k,m,n)     = tvar(k,m,n)     + svar
```


Well Designed Model Experiments

Analysis of Model Results

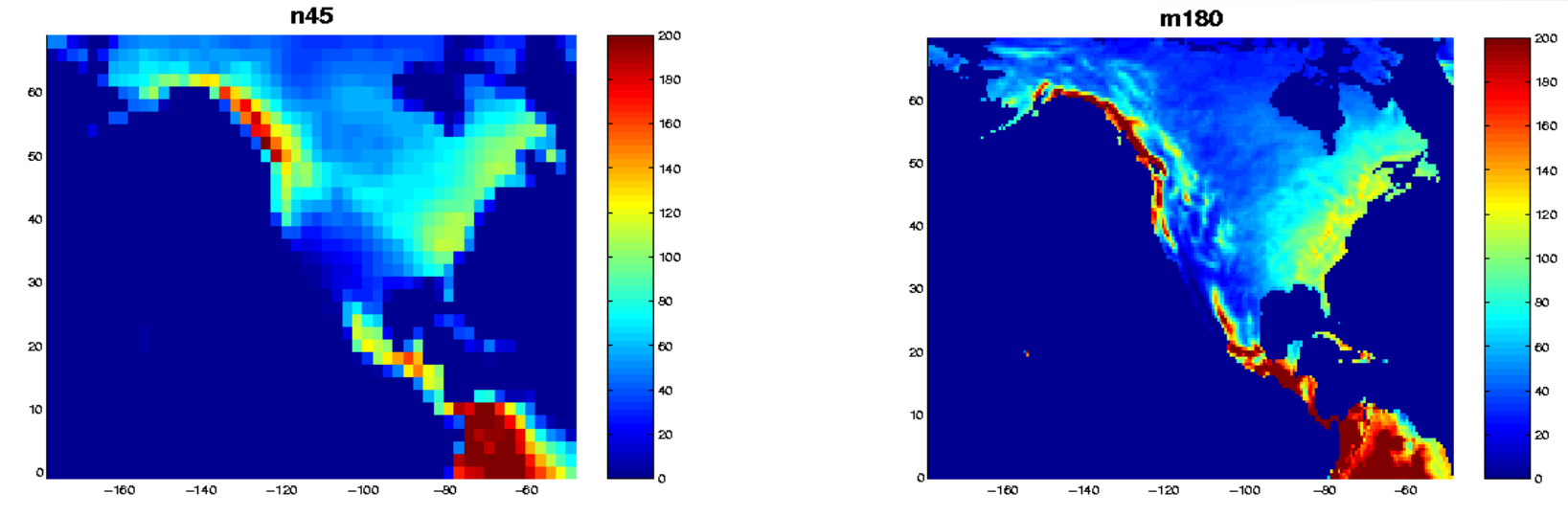


# Model resolution over time

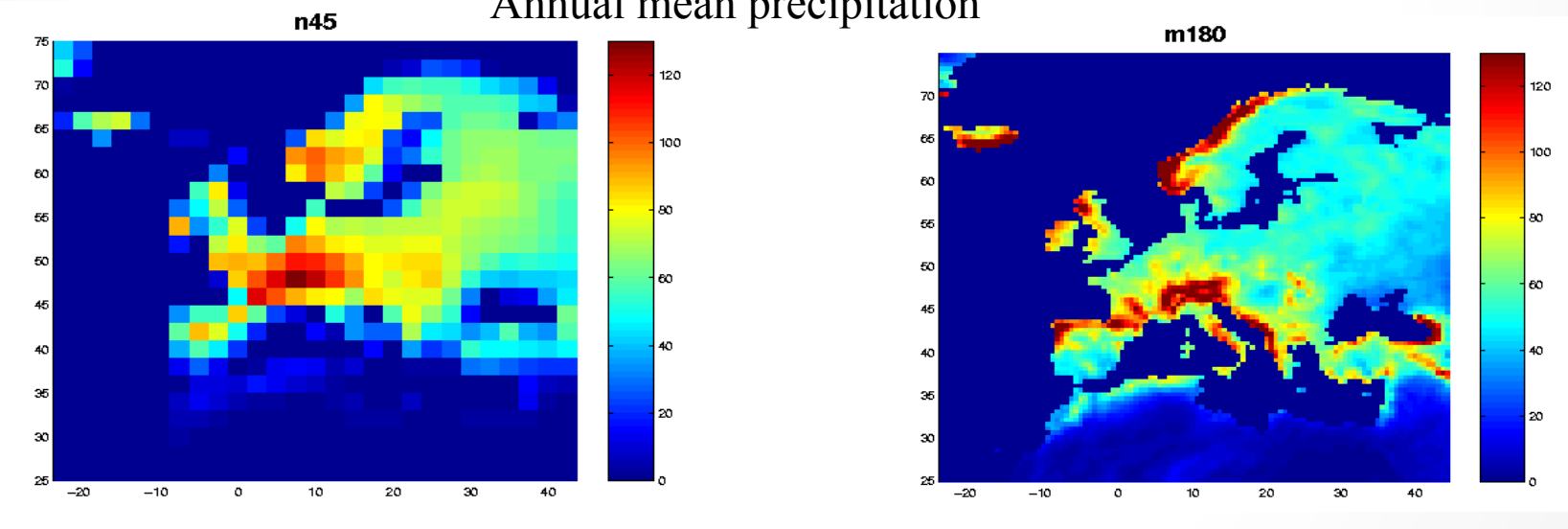


200 km

50 km



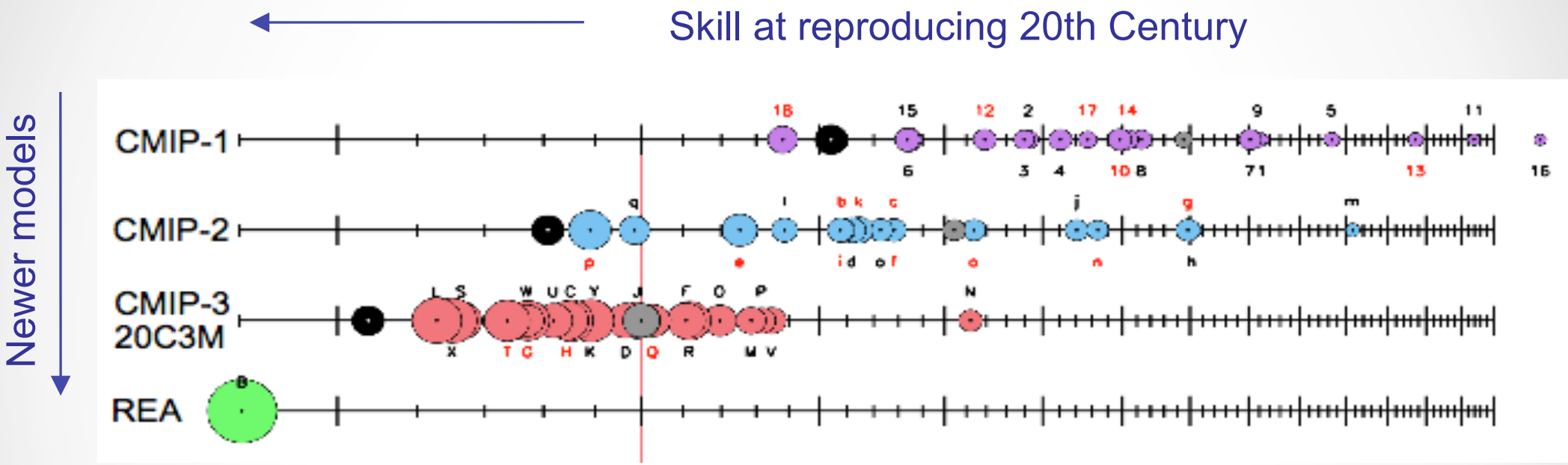

Annual mean precipitation




GFDL Atmos. ca. 2007

GFDL Atmos. ca. 2011

# Climate Model Fidelity to Climatology Has Steadily Improved




*Reichler and Kim (2008, BAMS)*

- Skill increasing with time
- Multi-model average better than any individual model
- Ability to reproduce climatology not necessarily projection skill

# Prediction vs. Projection

WeatherZine
Edition Number 26, February 2001

http://sciencepolicy.colorado.edu/zine/archives/1-29/26/guest.html

## Prediction versus Projection – Forecast versus Possibility

Mike MacCracken U.S. Global Change Research Program

**A *prediction* is a probabilistic statement that something will happen in the future based on what is known today.**

***a projection is a probabilistic statement that it is possible that something will happen in the future if certain conditions develop.***