

DILBERT



## Class 8: Causes of Recent Warming

- How much warming have we observed?
- Can we separate human vs. natural causes for warming?

### Learning Objectives

1. Understand and be able to plot the trend of temperature observations over the last ~125 years. (1)
2. Identify what climatic indicators have been used to support the conclusion that climate change is occurring on decadal time scales and how these indicators work. (2)
3. Explain the details of one method used to identify the source of recent atmospheric CO<sub>2</sub> increases as caused by human activities (2,3)
4. Describe three pieces of evidence that demonstrate how anthropogenic CO<sub>2</sub> emissions are directly increasing the greenhouse effect (1)

# Review: Carbon Cycle

**Atmosphere (600, Preindustrial)**

100

100

**Surface Ocean  
(1,000)**

100

100

**Plants/Soils  
(2,000)**

37

37

**Deep Ocean  
(40,000)**

**Fossil Fuels  
(5,000)**

0.2

**Rocks and  
Sediments  
(65,995,000)**

0.1

# Human Carbon Emissions



Burning Fossil Fuels

$9.9 \pm 0.5 \text{ GtC/y}$



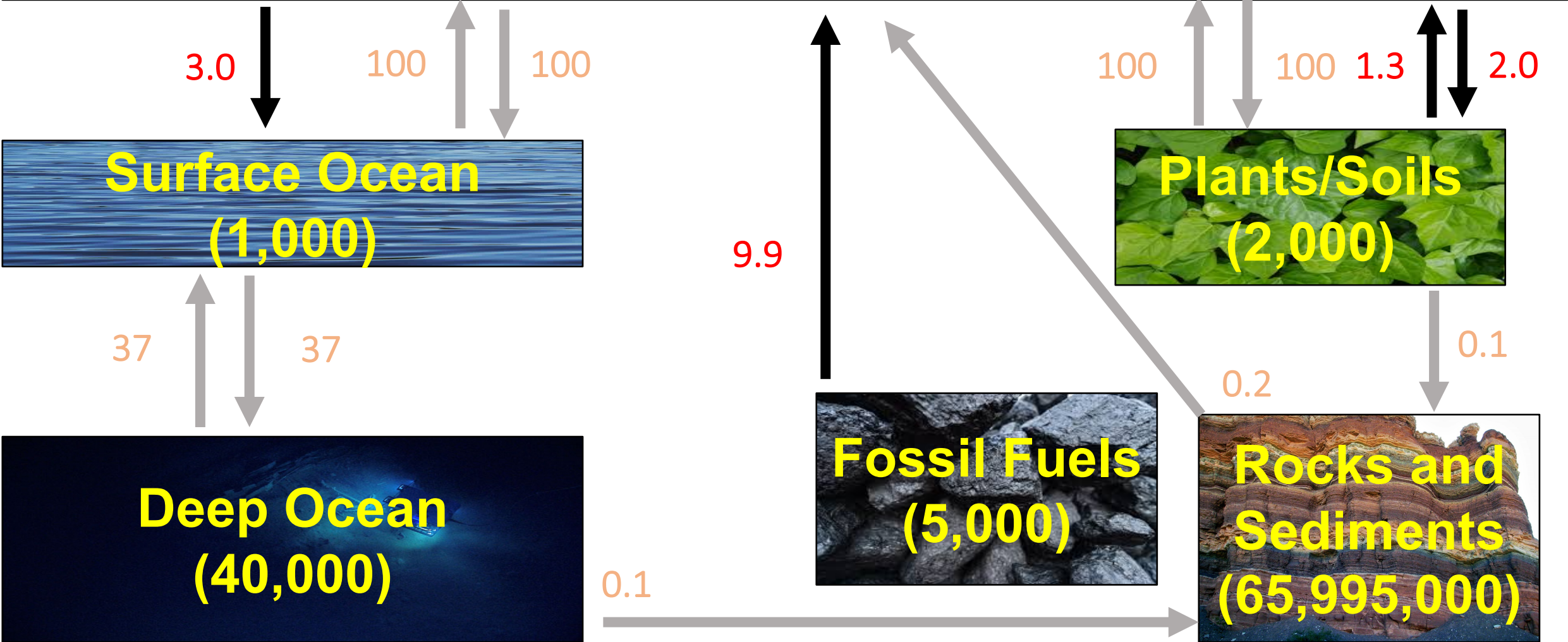
Land Use Change

$1.3 \pm 0.5 \text{ GtC/y}$

Data from  
World  
Meteorological  
Organization

# Review: Carbon Cycle

**Atmosphere (750) + 6.2**



# Review: Carbon Cycle Feedbacks

## Negative Feedbacks



Increased plant  
photosynthesis  
/growth

Increased  
chemical  
weathering

## Positive Feedbacks



Permafrost  
Melt

Reduced  
Ocean Carbon  
Uptake

# Today: Causes of Recent Warming

# Testing This Statement

**Human-made CO<sub>2</sub> emissions are causing global warming**

# Testing This Statement

## Human-made CO<sub>2</sub> emissions are causing global warming

- When have we been emitting?
- How much have we been emitting?
- How have we been emitting?
- What have we been emitting?



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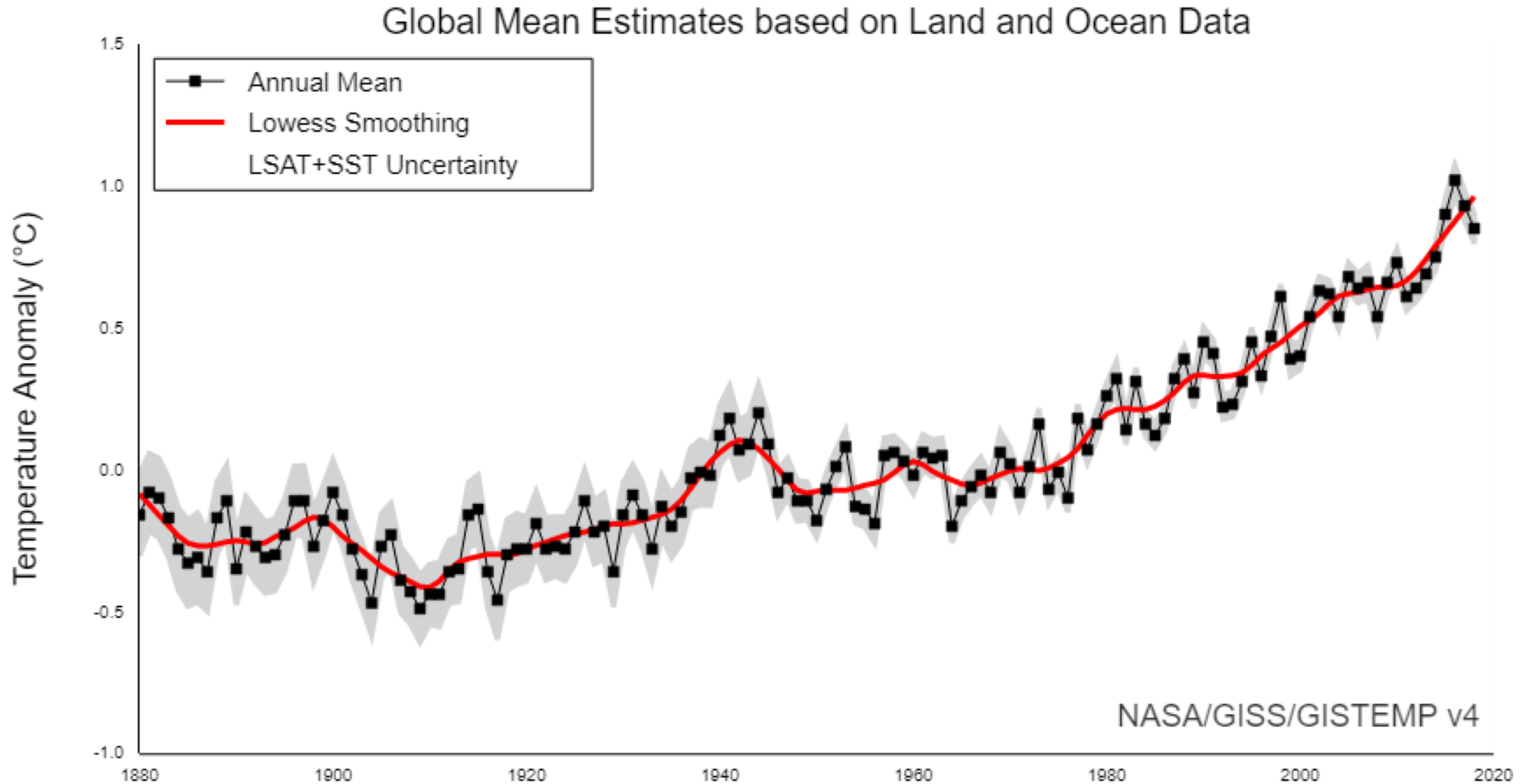
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- What would record/happen if it was getting hotter?
- Do we have enough data?

# Testing This Statement

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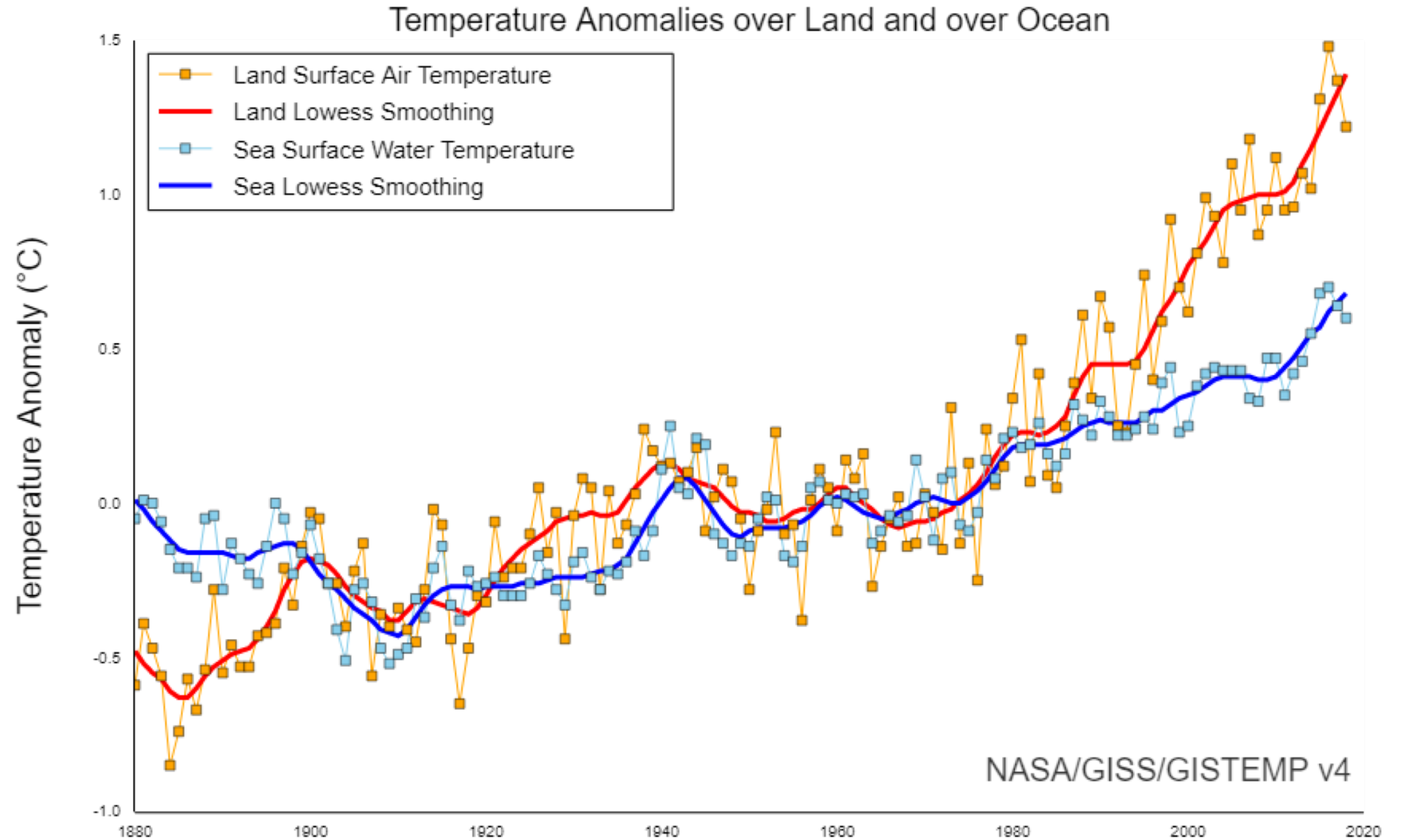
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# Global Warming Observations



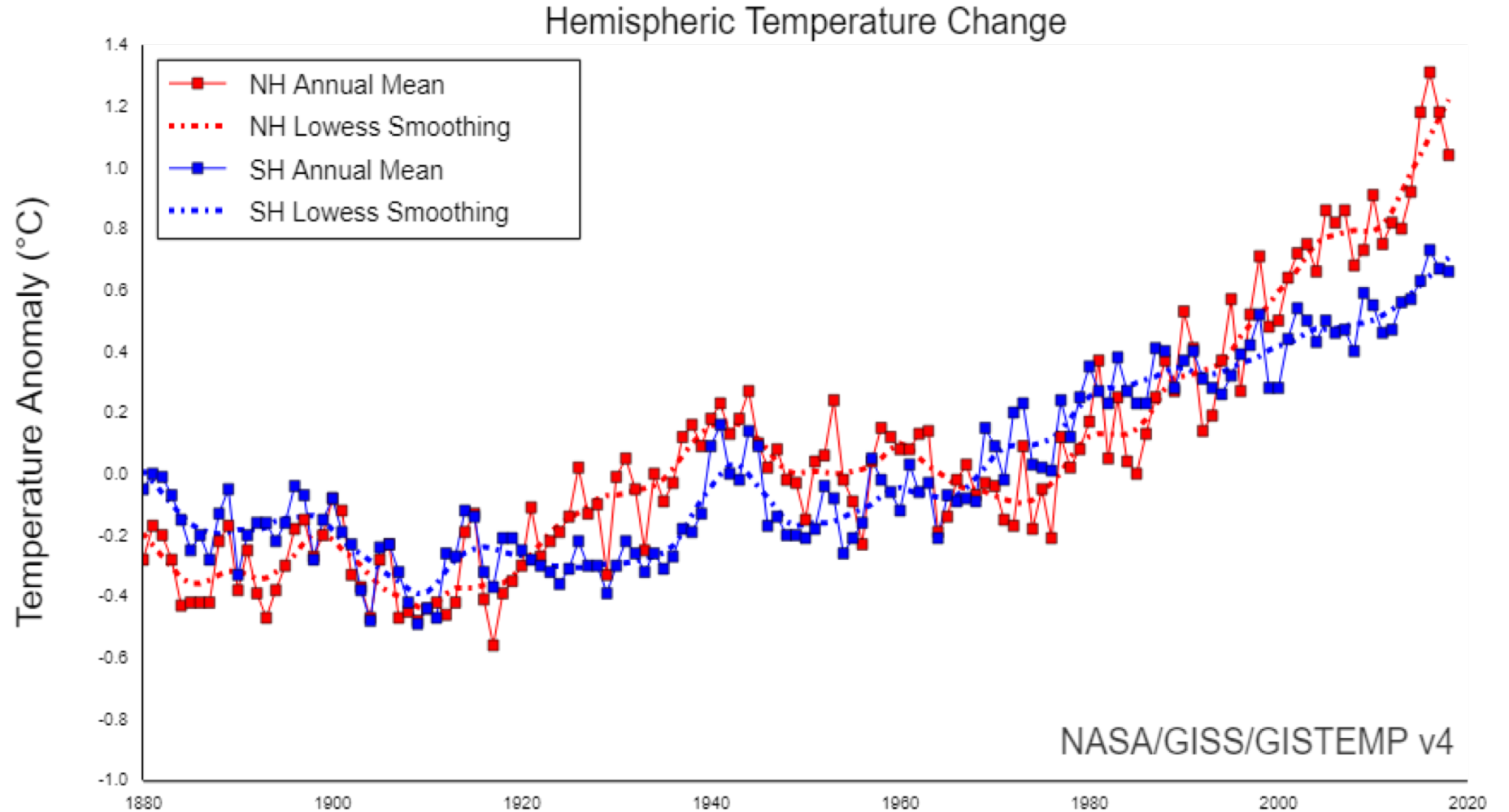
# Global Warming Observations

Both land and oceans are warming



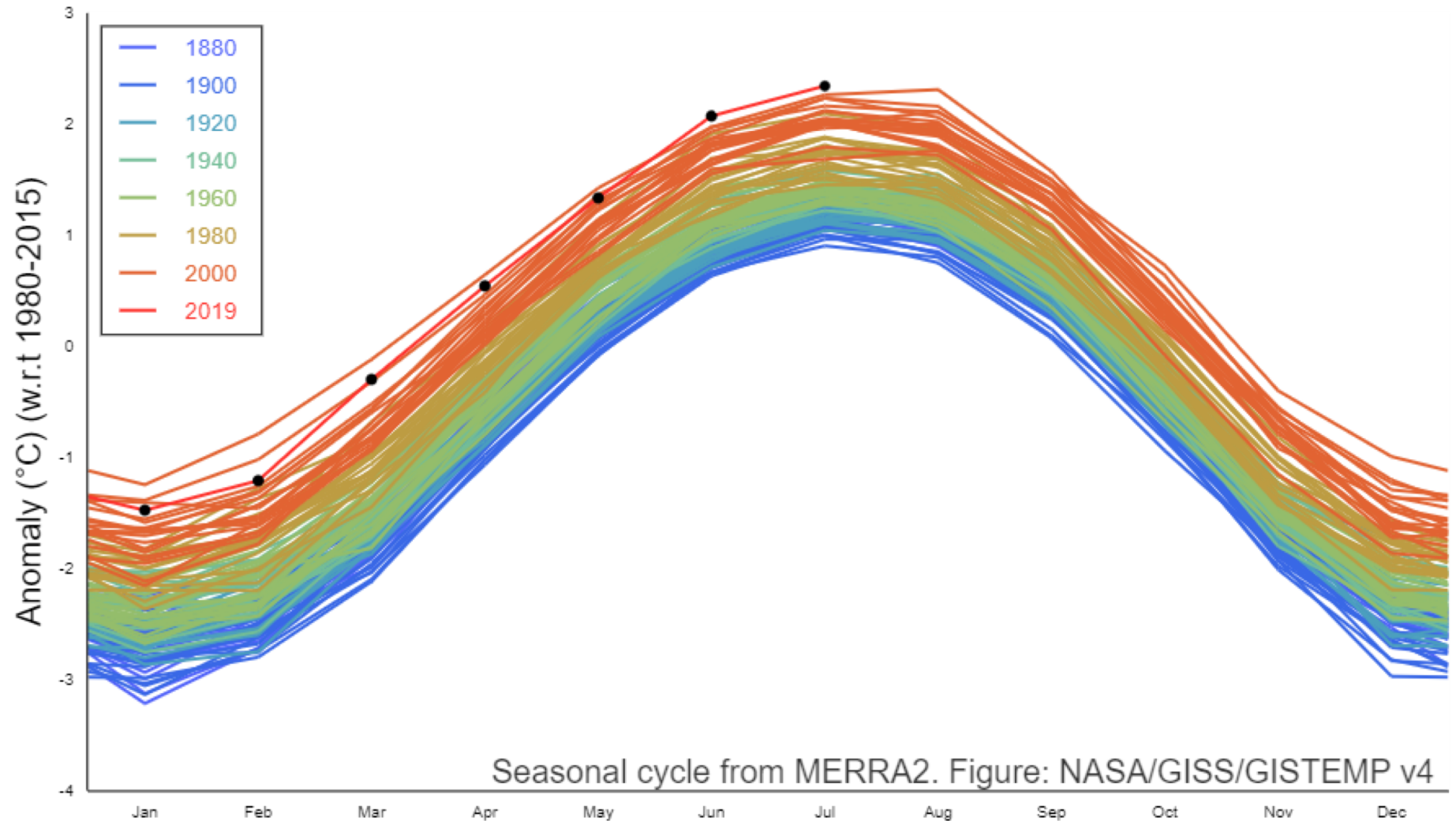
# Global Warming Observations

North and South Hemisphere are both warming



# Global Warming Observations

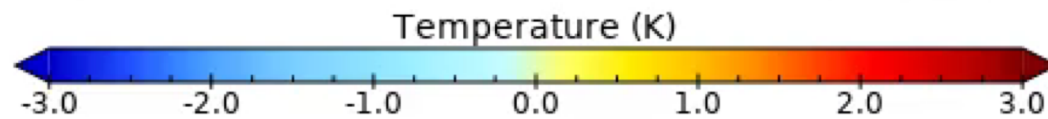
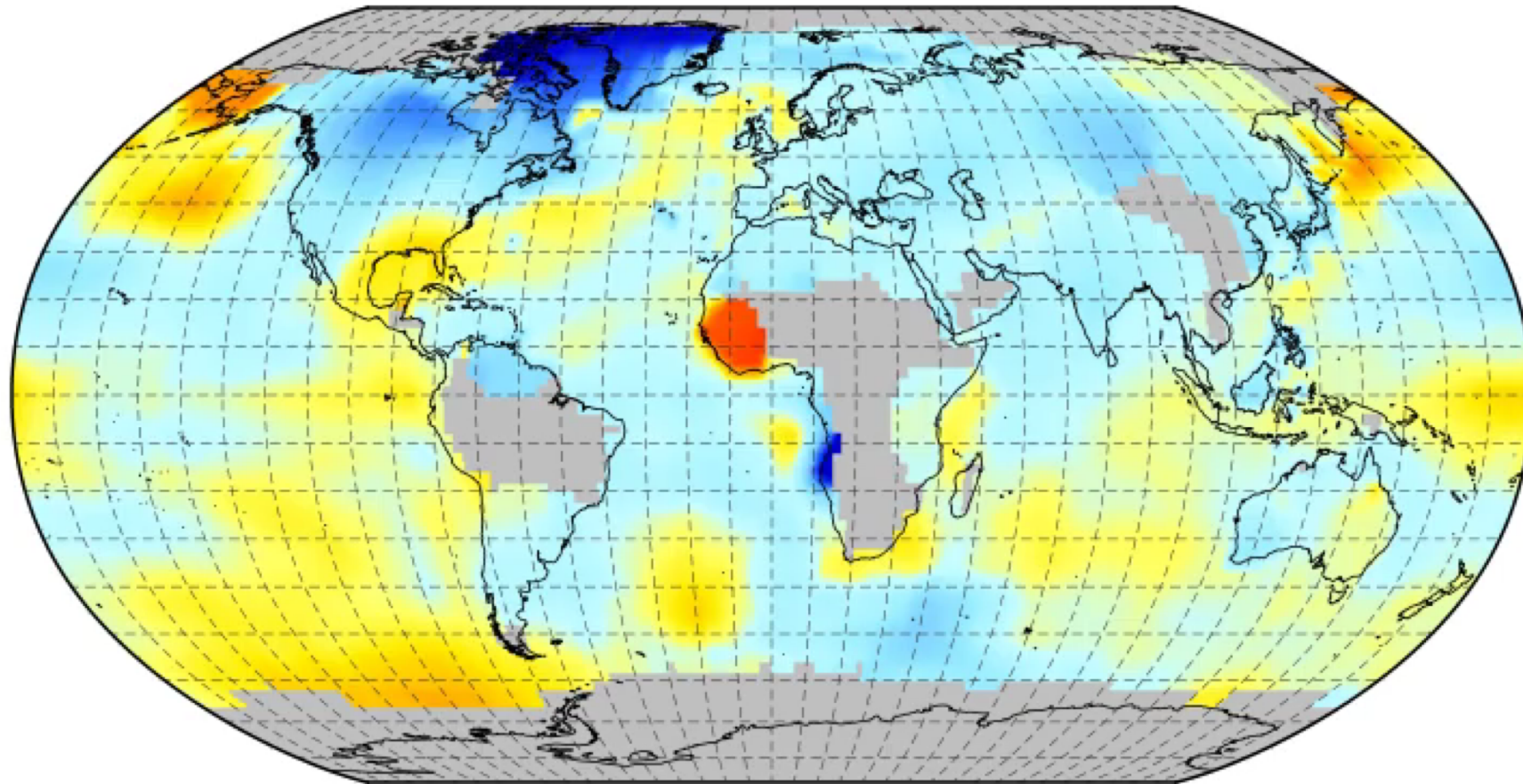
GISTEMP Seasonal Cycle since 1880



Warming in  
all seasons

# Global Warming Observations

Annual Surface Temperature Anomaly base 1951-1980  
1880-1884



Data Min = -3.5, Max = 1.8, Mean = -0.2

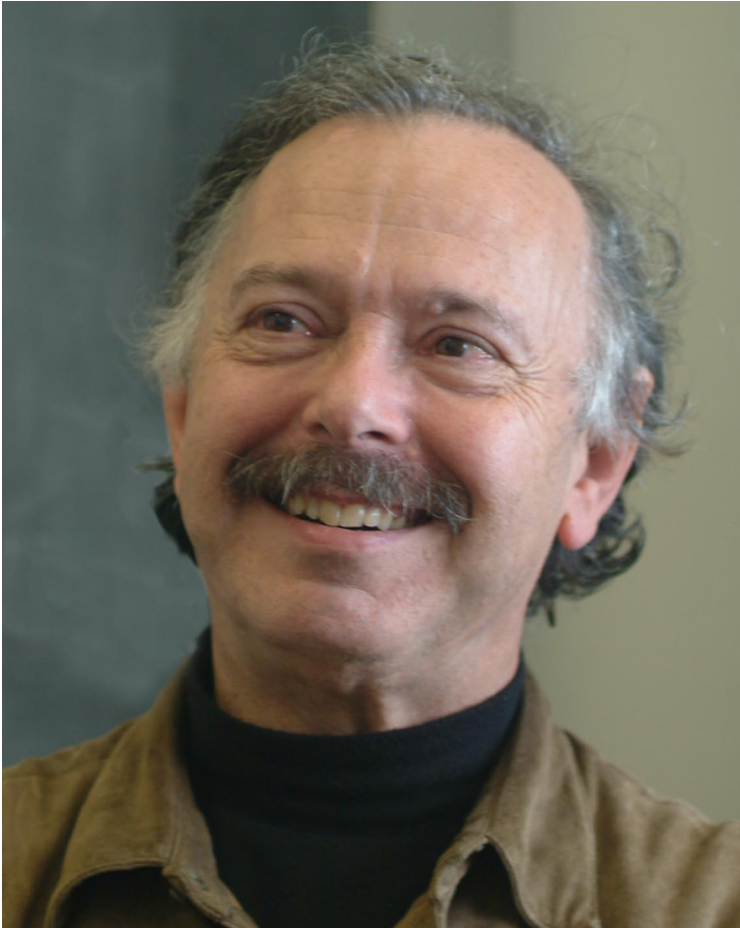
Data from  
NASA GISS



Warming Observations: Do we have enough/good data?

# Do we have enough/good data?

Dr. Richard Muller, UC Berkeley physicist, asked this exact question and investigated



Opinion | OP-ED CONTRIBUTOR

## The Conversion of a Climate-Change Skeptic

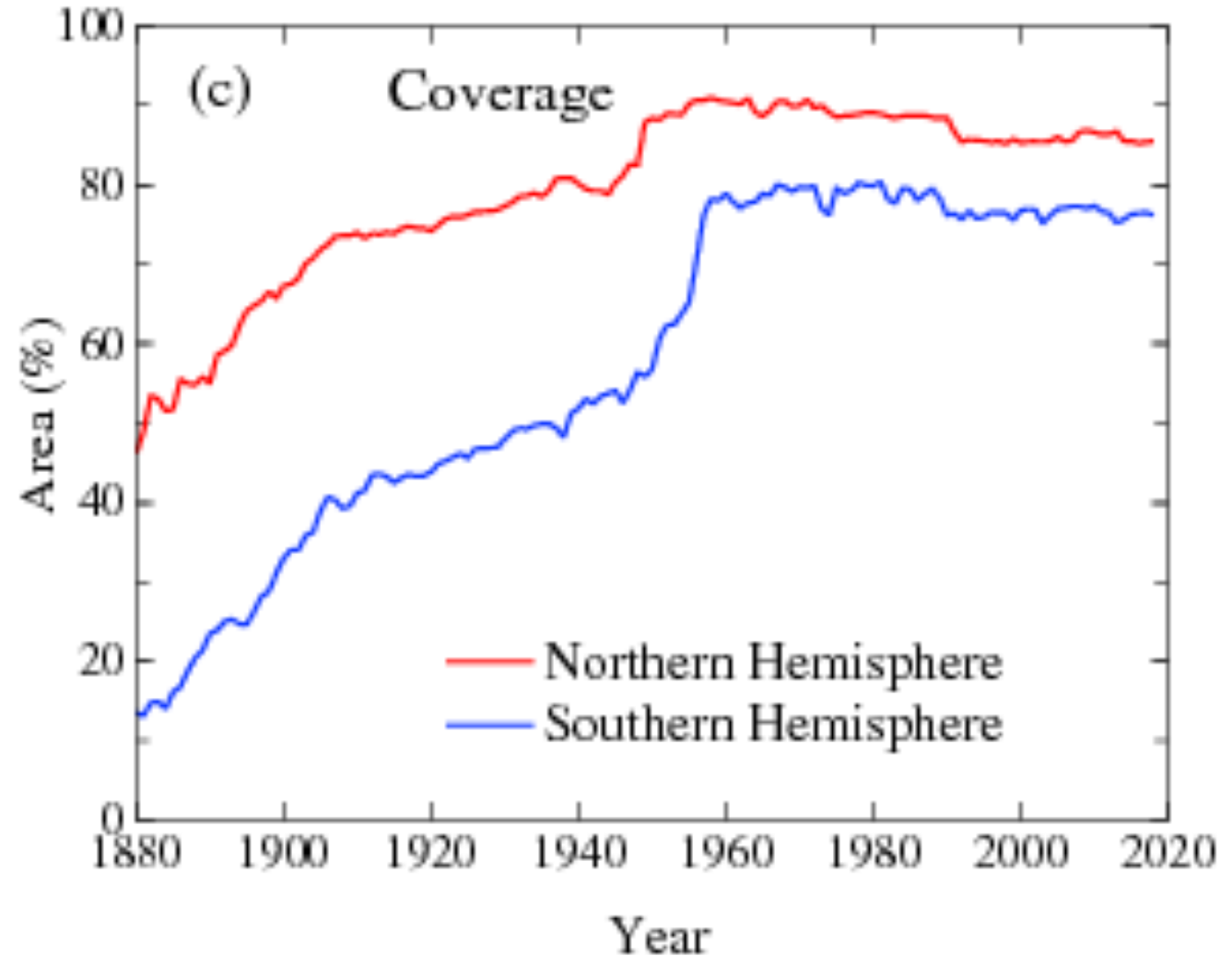
By RICHARD A. MULLER JULY 28, 2012

Berkeley, Calif.

CALL me a converted skeptic. Three years ago I identified problems in previous climate studies that, in my mind, threw doubt on the very existence of global warming. Last year, following an intensive research effort involving a dozen scientists, I concluded that global warming was real and that the prior estimates of the rate of warming were correct. I'm now going a step further: Humans are almost entirely the cause.

# Do we have enough/good data?

Good spatial and temporal data coverage

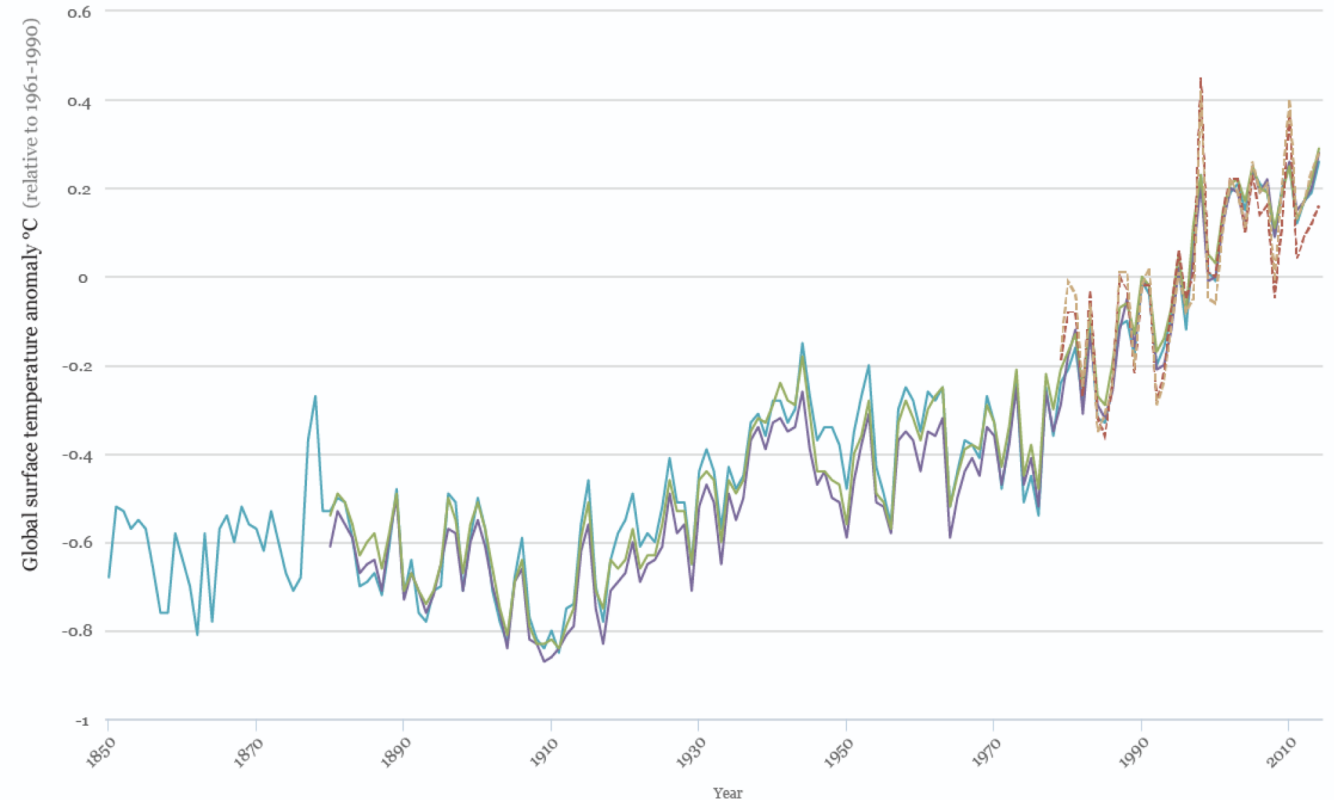


# Do we have enough/good data?

Major global temperature datasets agree

Figure from *CarbonBrief.org*

### How do the global temperature datasets compare?



The Carbon Brief

RSS

UAH

Met Office/CRU

NASA

NOAA



Lower troposphere temperature



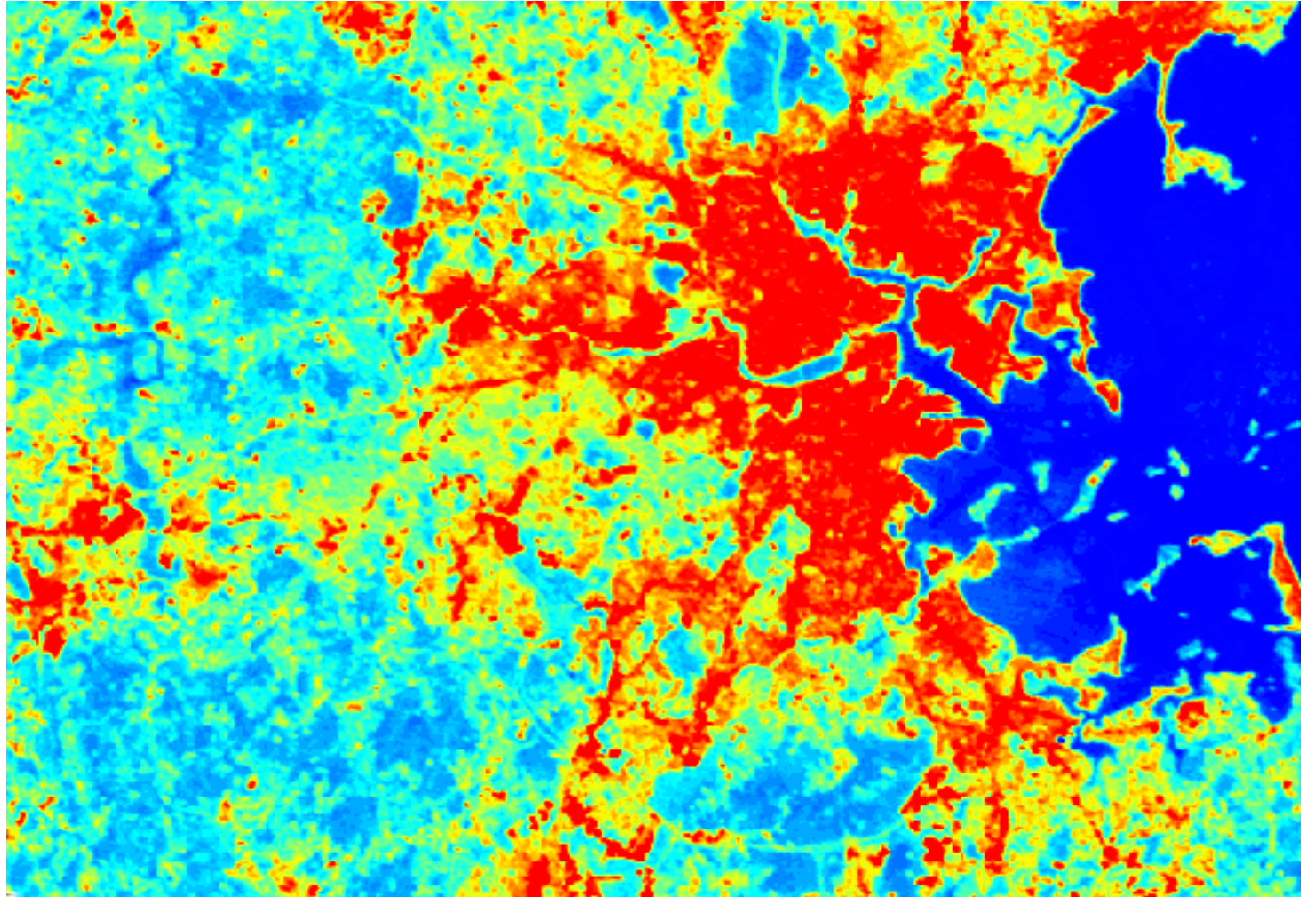
Surface temperature

# Do we have enough/good data?

What about the effect of urban heat islands?

Cities are usually warmer than surrounding country...

Are thermometers just recording urban expansion?



# Do we have enough/good data?

Not much difference in urban vs. rural records...

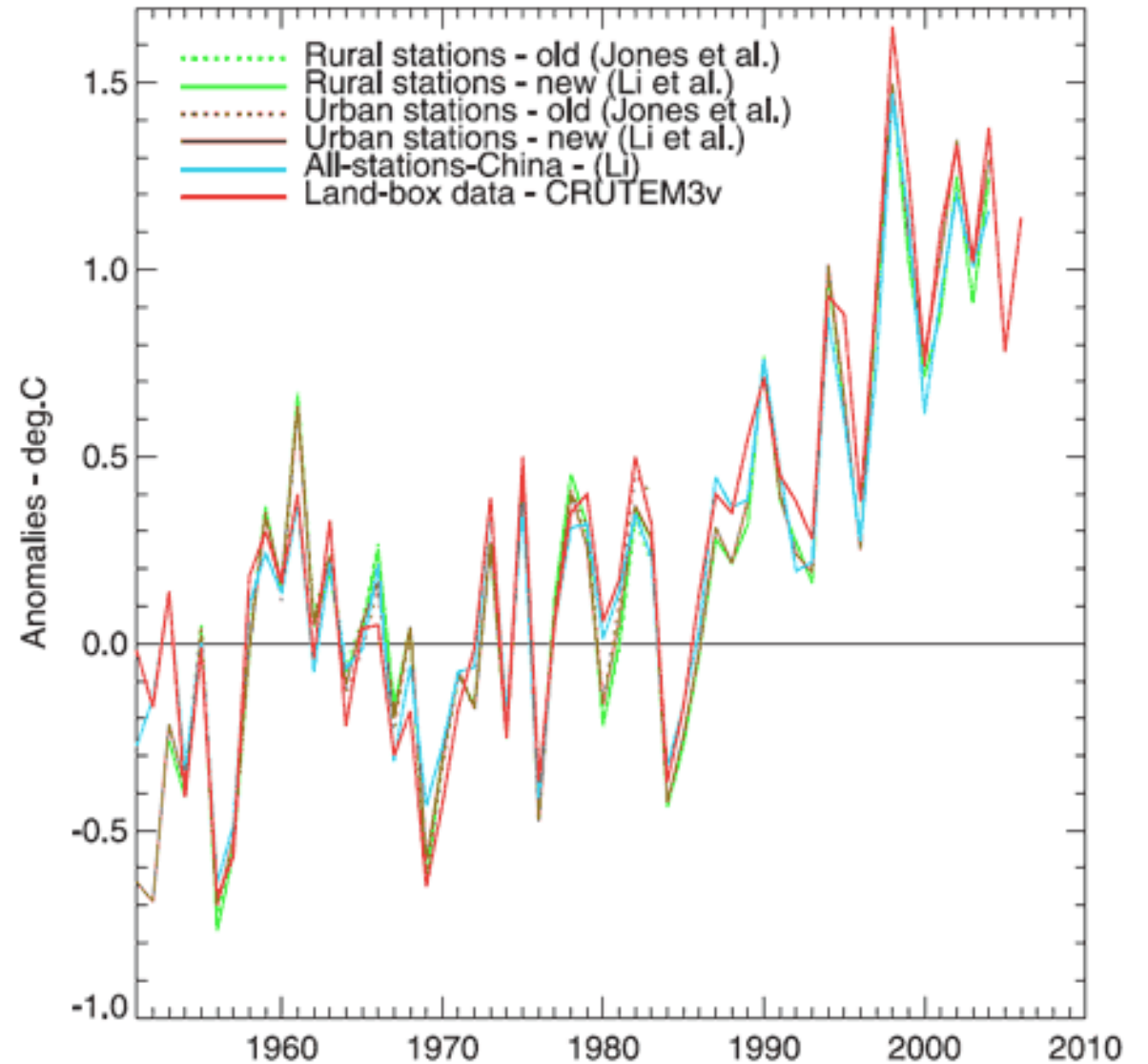
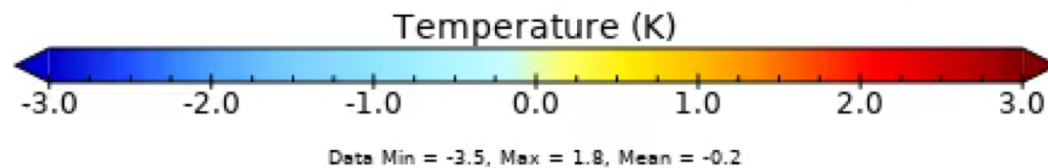
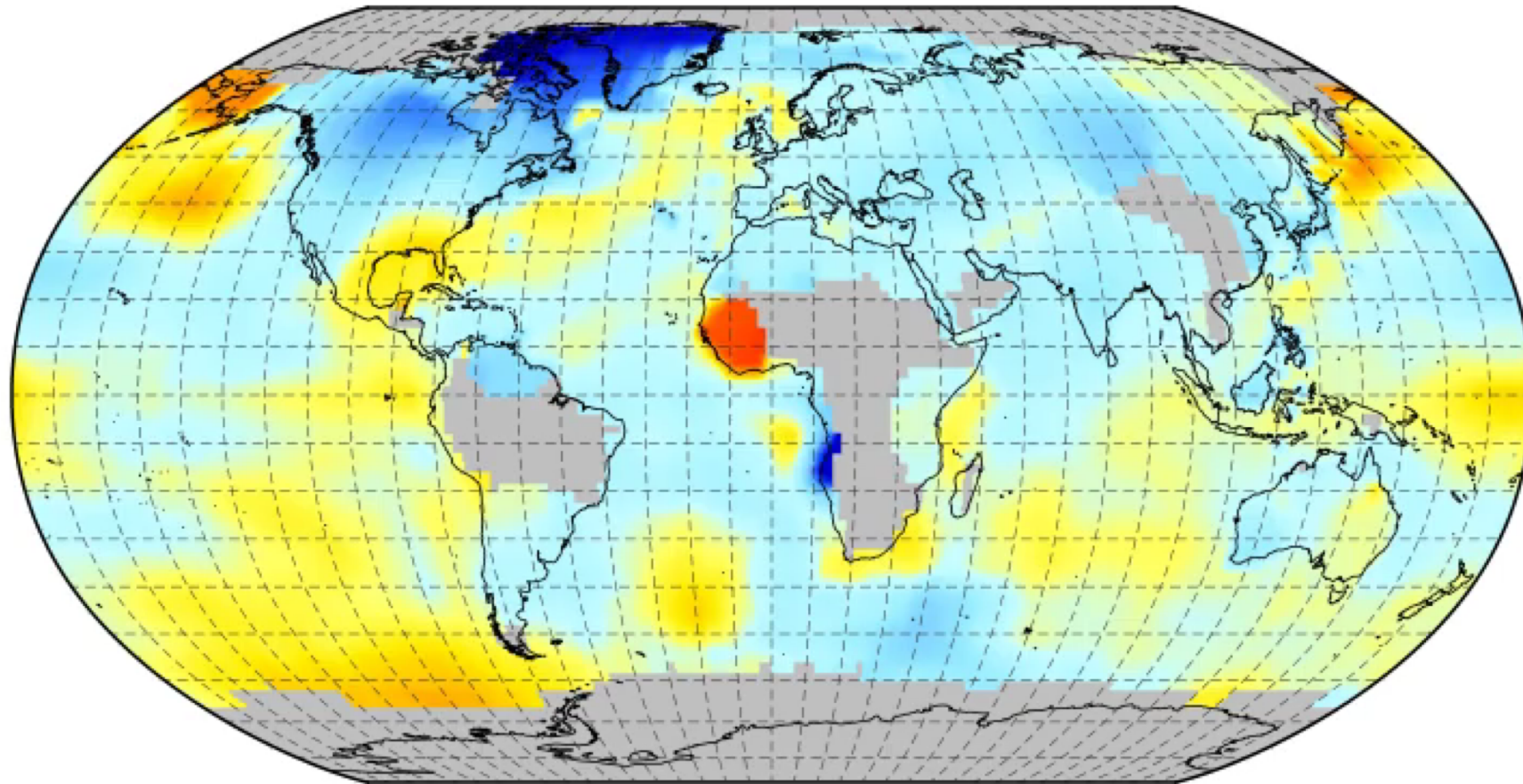


Figure from *SkepticalScience.com*

# Do we have enough/good data?

Annual Surface Temperature Anomaly base 1951-1980  
1880-1884



Data from  
NASA GISS

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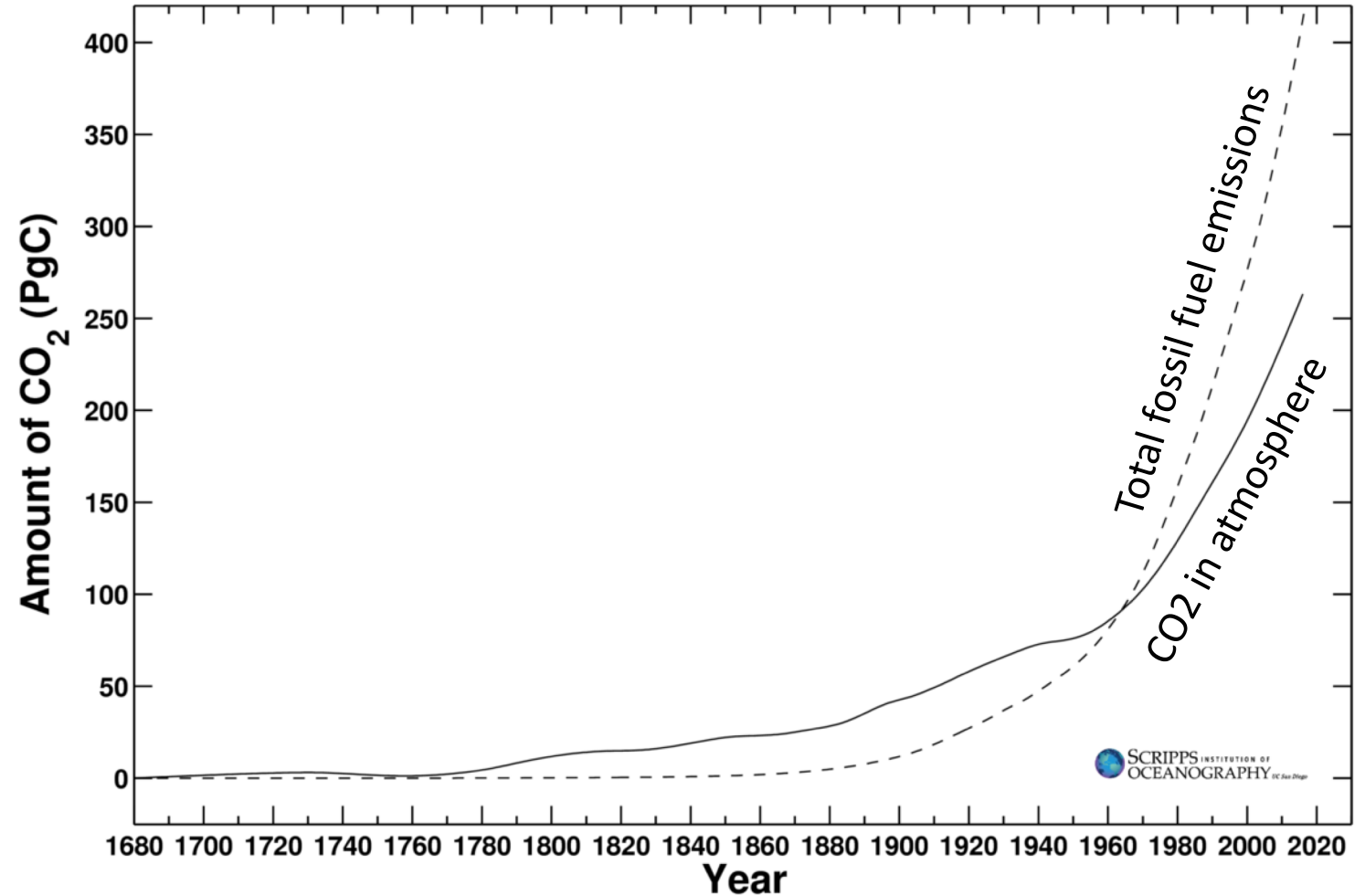
# When have we been emitting?

Since industrial revolution

Atmospheric CO<sub>2</sub> starts rising around same time

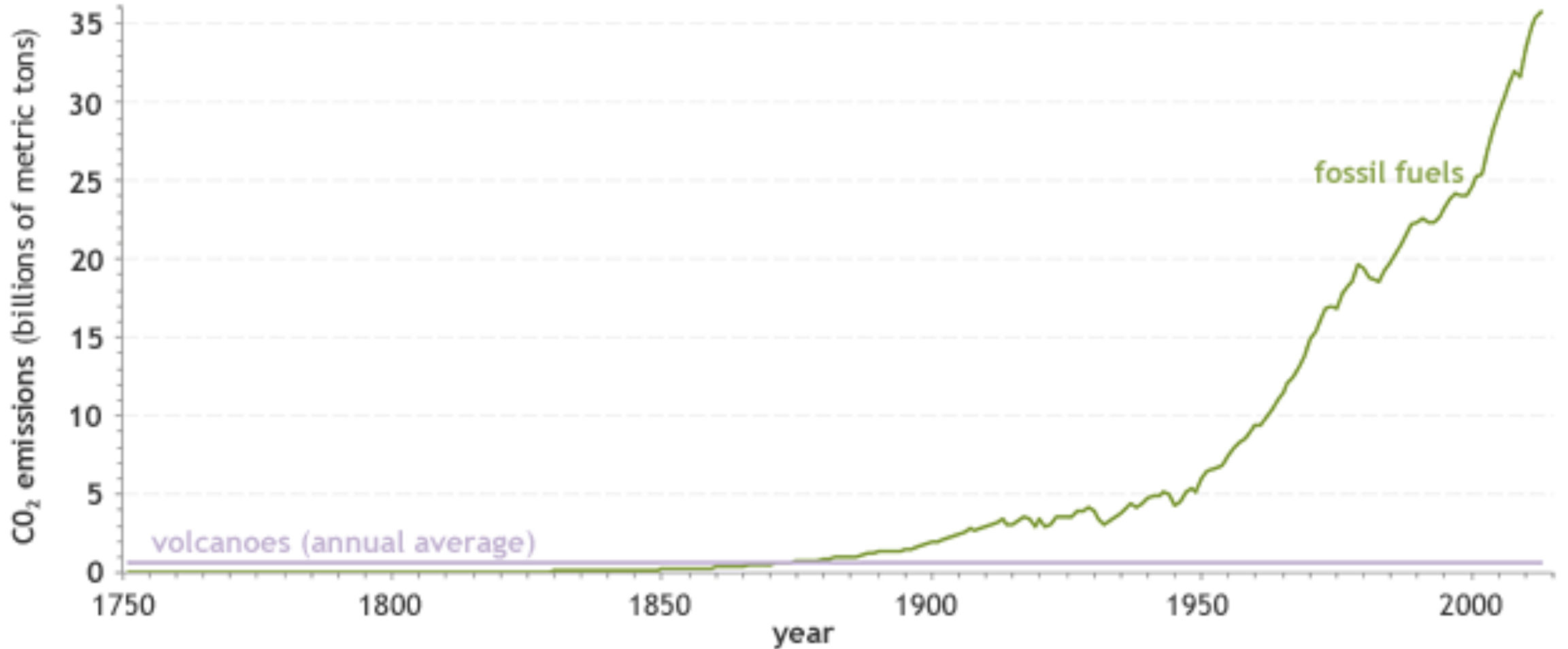
**Cumulative Fossil Fuel with Atmospheric CO<sub>2</sub> Increase**

Last updated July 2017



# How much have we been emitting?

Fossil fuel versus volcanic emissions



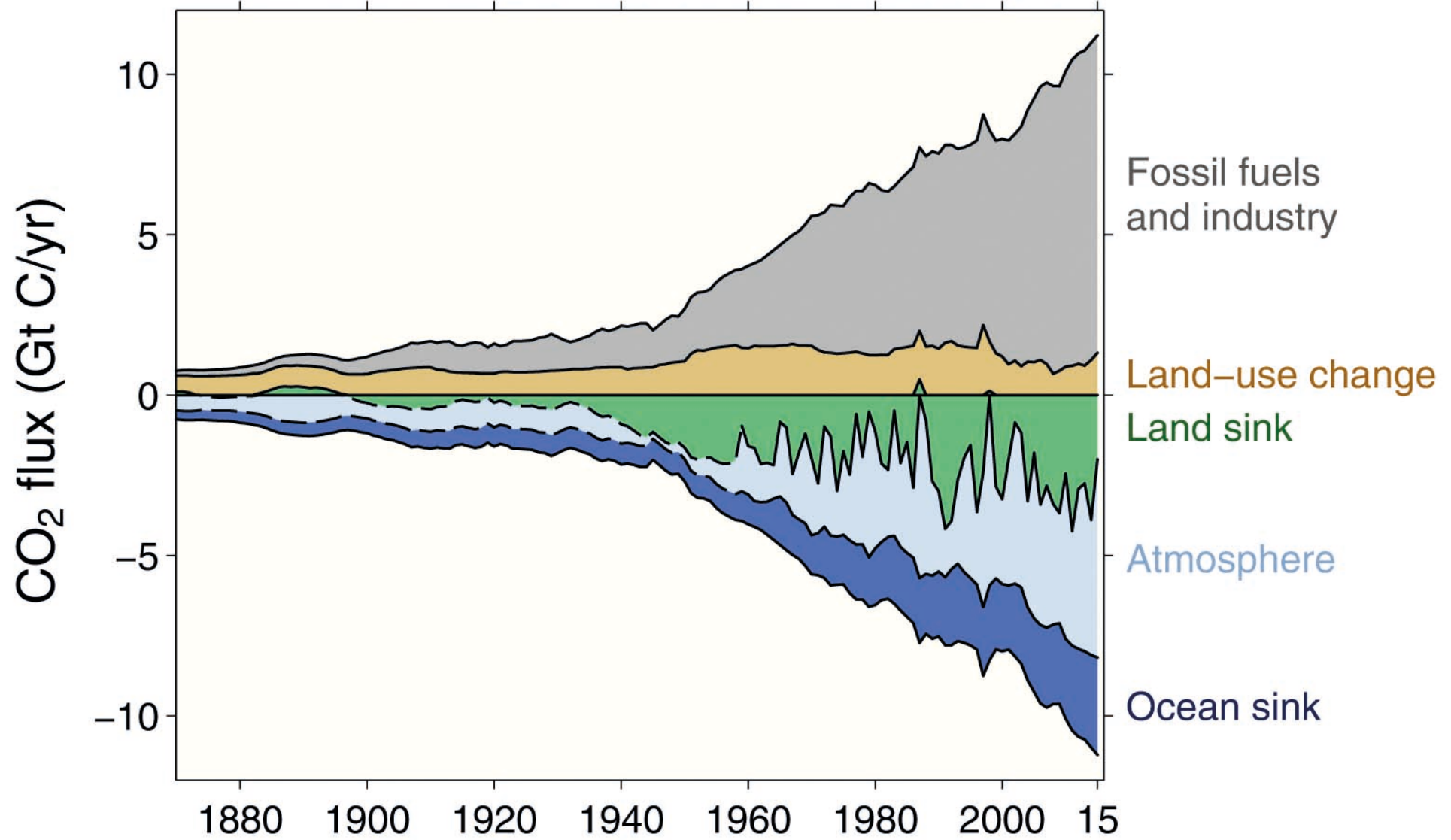
NOAA Climate.gov  
Data: CDIAC, Burton et al, 2013

# How have we been emitting?

Data: CDIAC/NOAA-ESRL/GCP/Joos et al 2013/Khaliwala et al 2013

Fossil fuels  
(increasing)

Land use  
change



# What have we been emitting?

Several types of greenhouse gas, mostly CO<sub>2</sub>

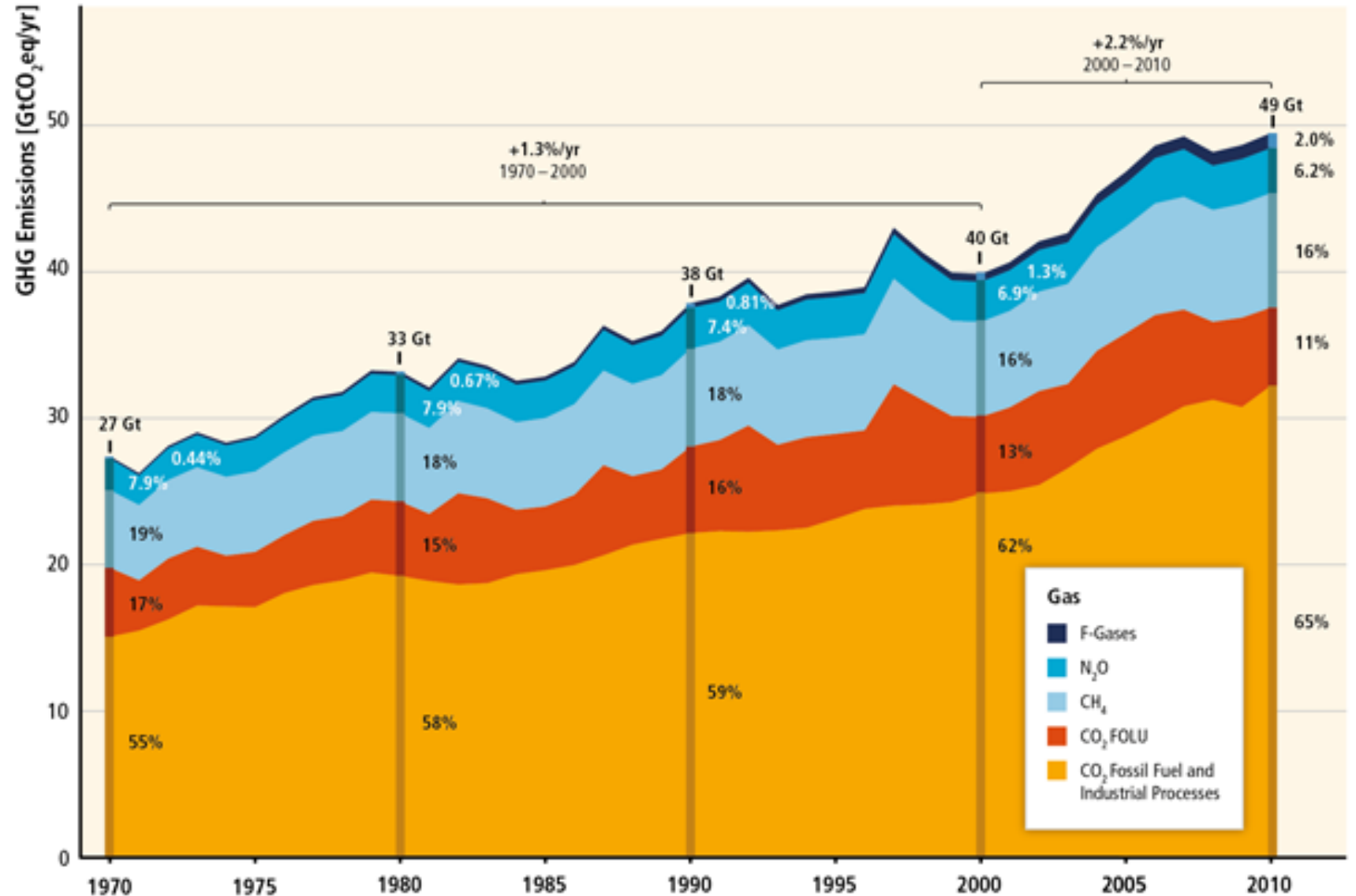


Figure from IPCC Fifth Assessment Report

# Testing This Statement

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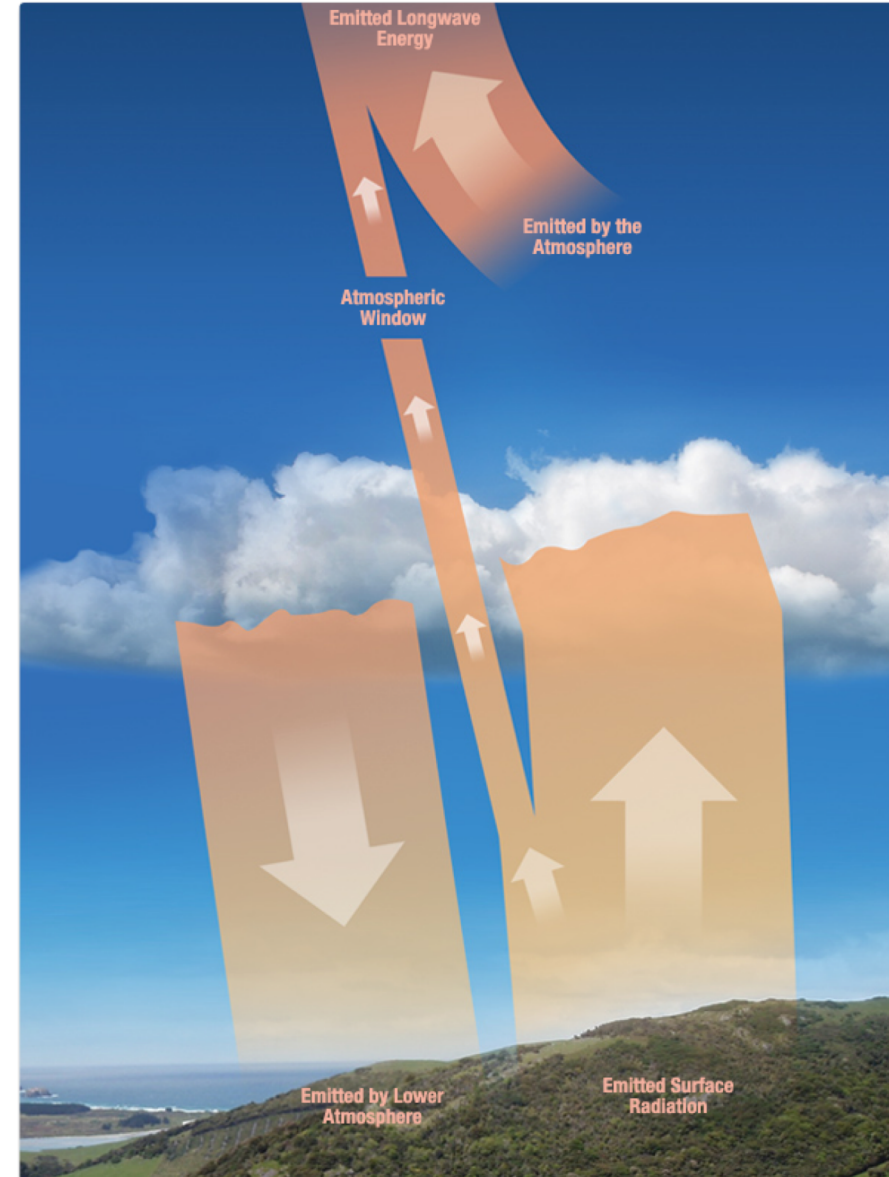
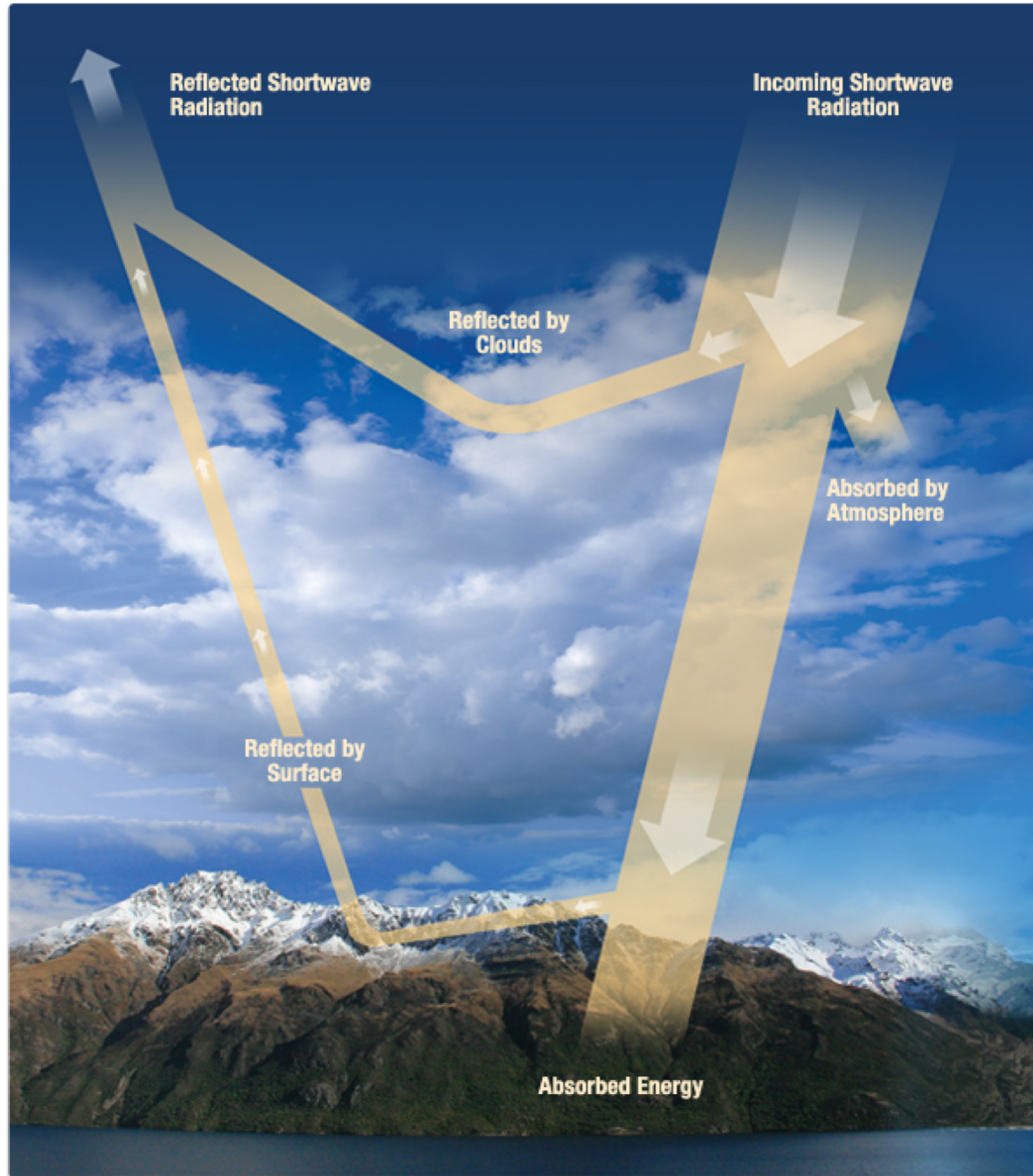
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# How does CO<sub>2</sub> cause heating?

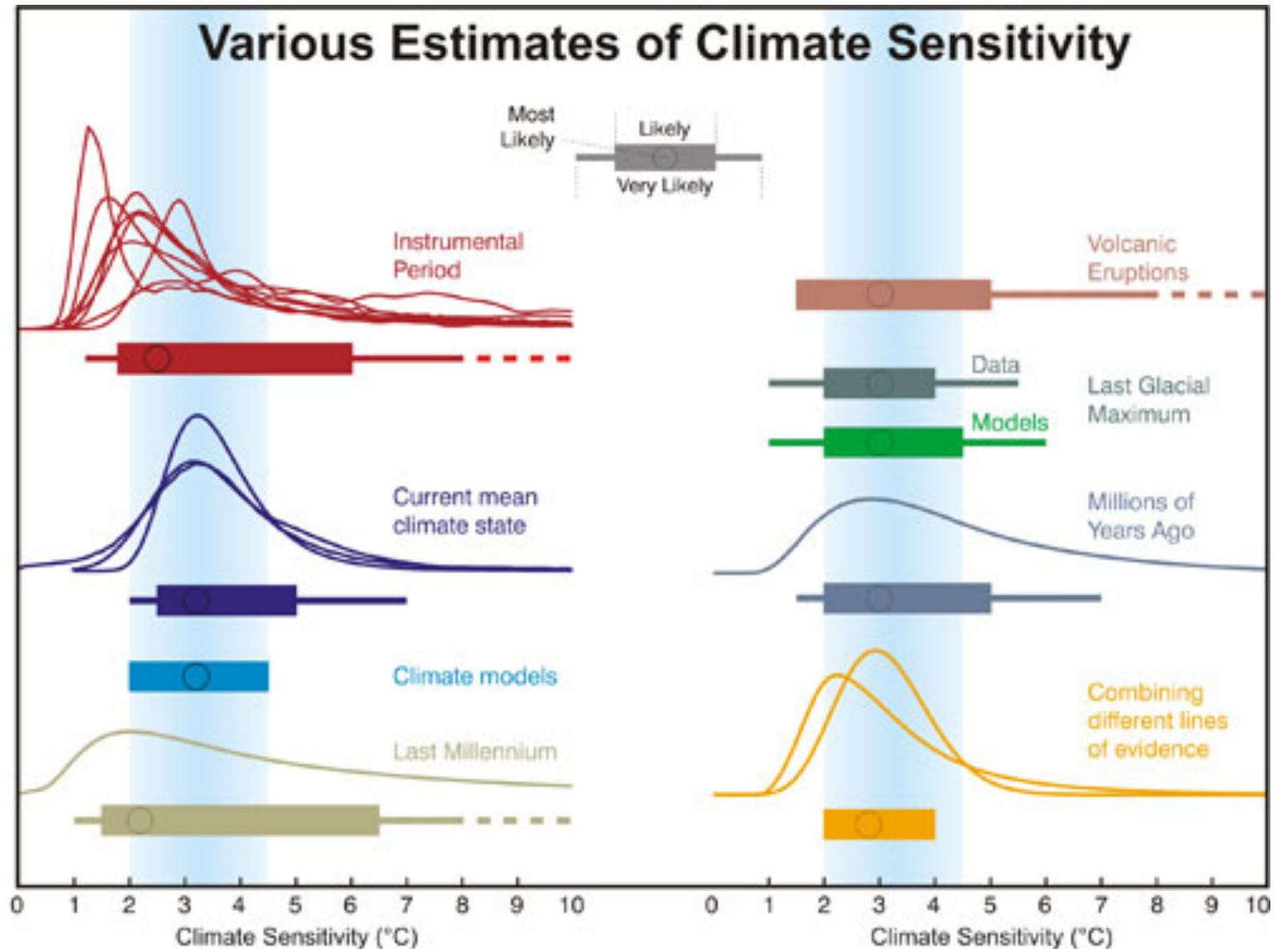




# How does CO<sub>2</sub> cause heating?

How sensitive is Earth climate to increased CO<sub>2</sub>?

Numerous lines of investigation agree on similar range of sensitivities



# How have other factors changed?

## Global Climate Drivers

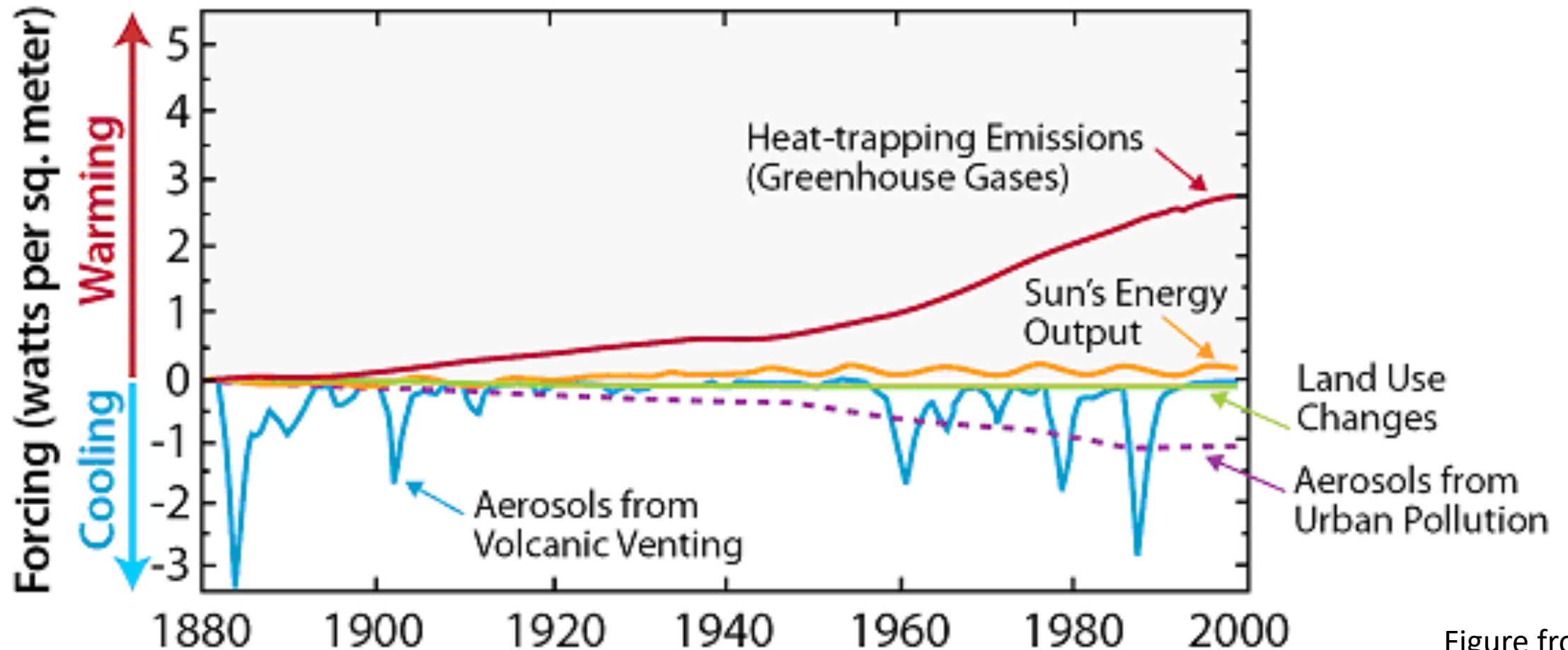
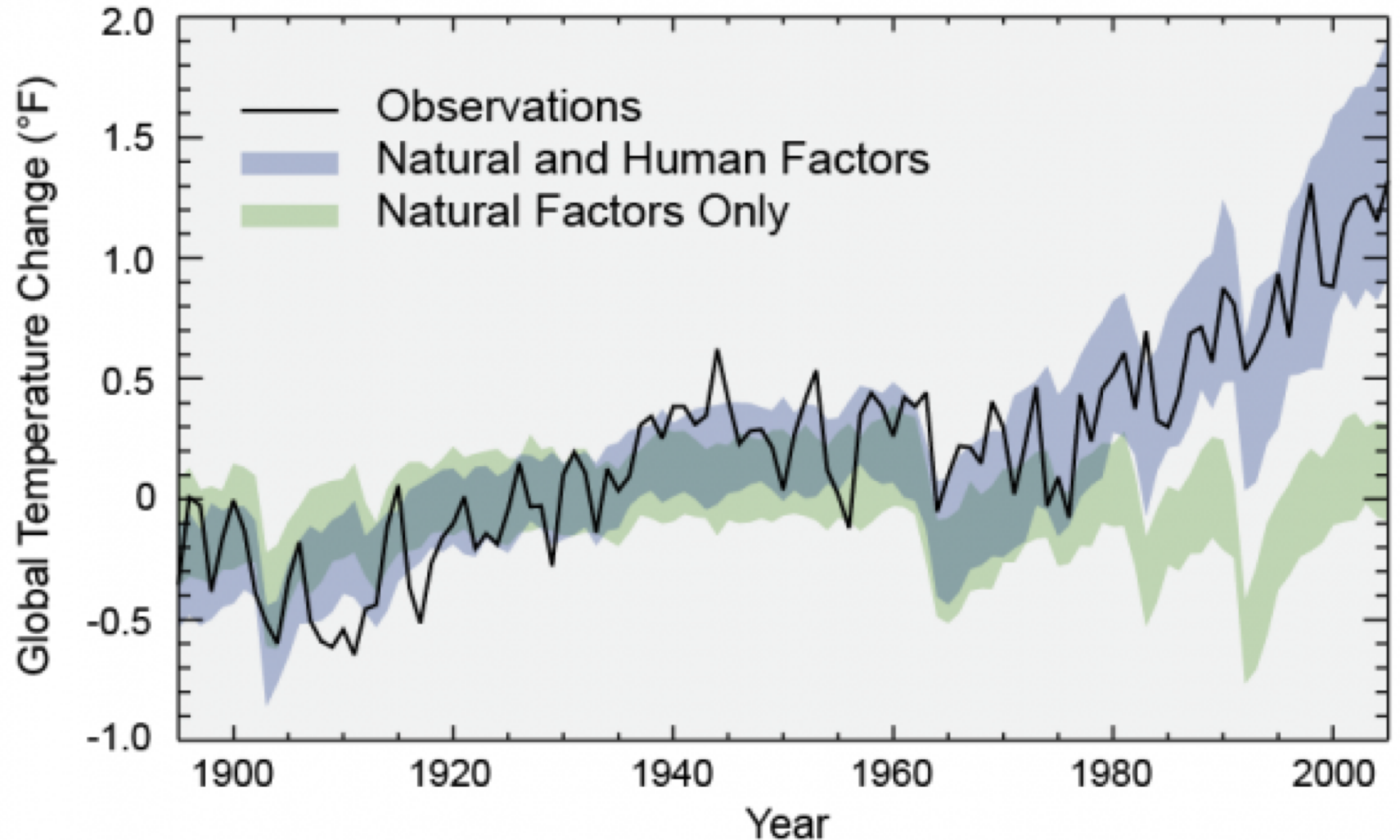


Figure from  
NASA GISS

# How have other factors changed?

Separating Human and Natural Influences on Climate



Climate models  
match  
observations  
with human  
influence only

Figure from  
*GlobalChange.gov*

# Where is heating happening?

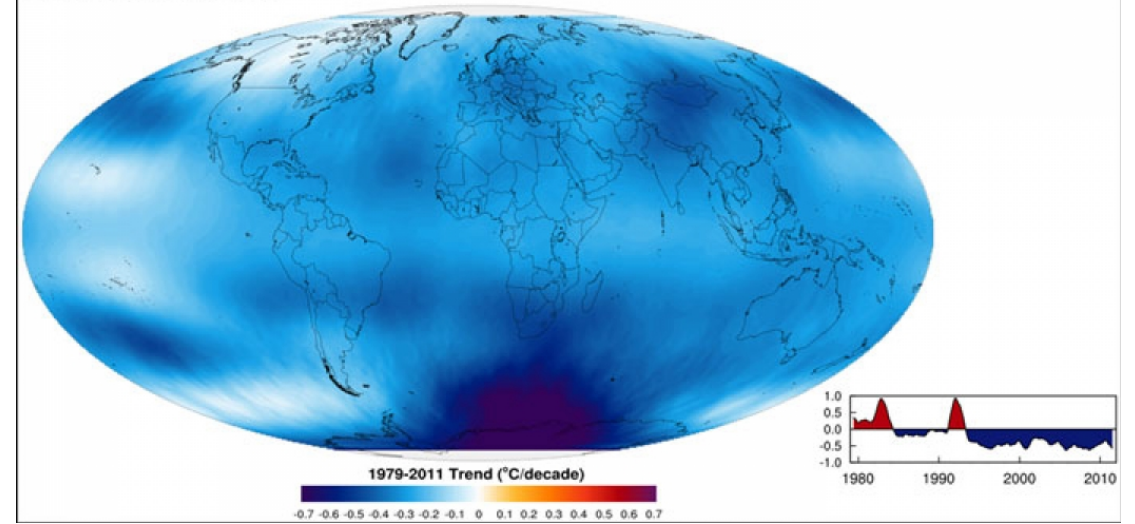
Atmospheric warming patterns match what we'd expect from human pollution and greenhouse gas emissions

## The Greenhouse Signature

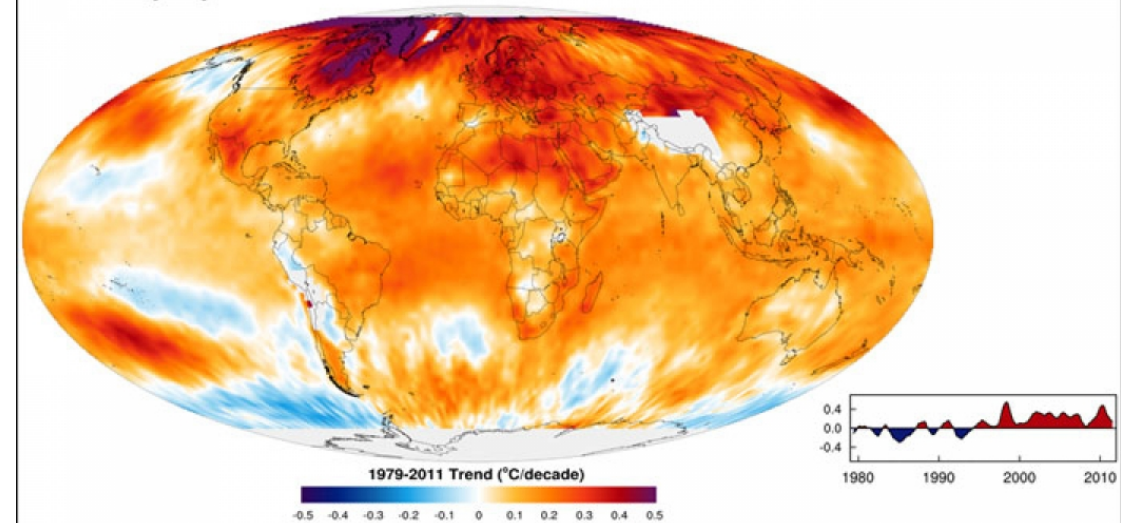


Figure from  
*GlobalChange.gov*

## Lower Stratosphere



## Lower Troposphere



How does today compare to the past?

(Paleoclimate Preview)

# How does today compare to the past?

Warmer than  
past 1,000 years

Even within  
statistical  
uncertainty  
(shaded area)

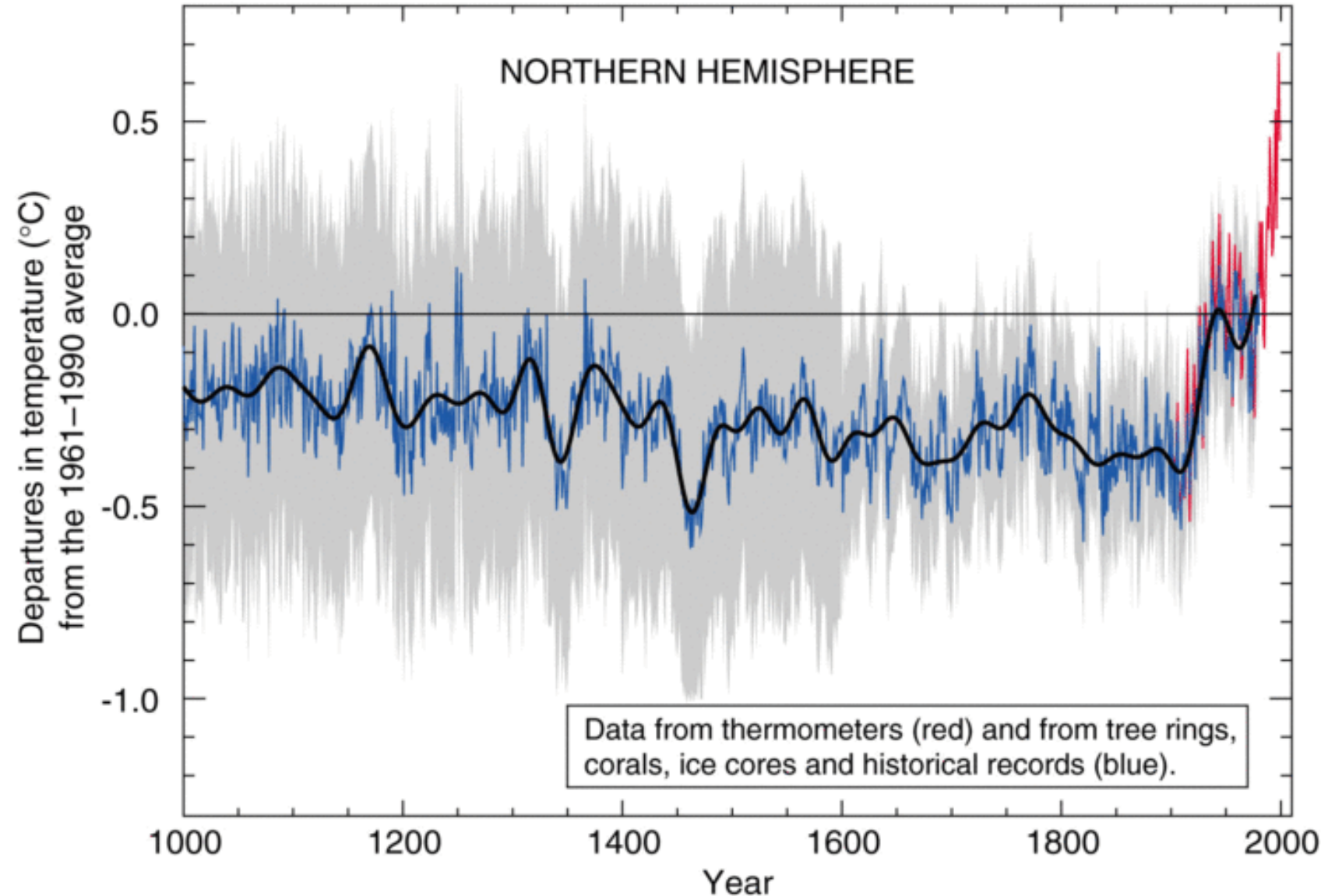
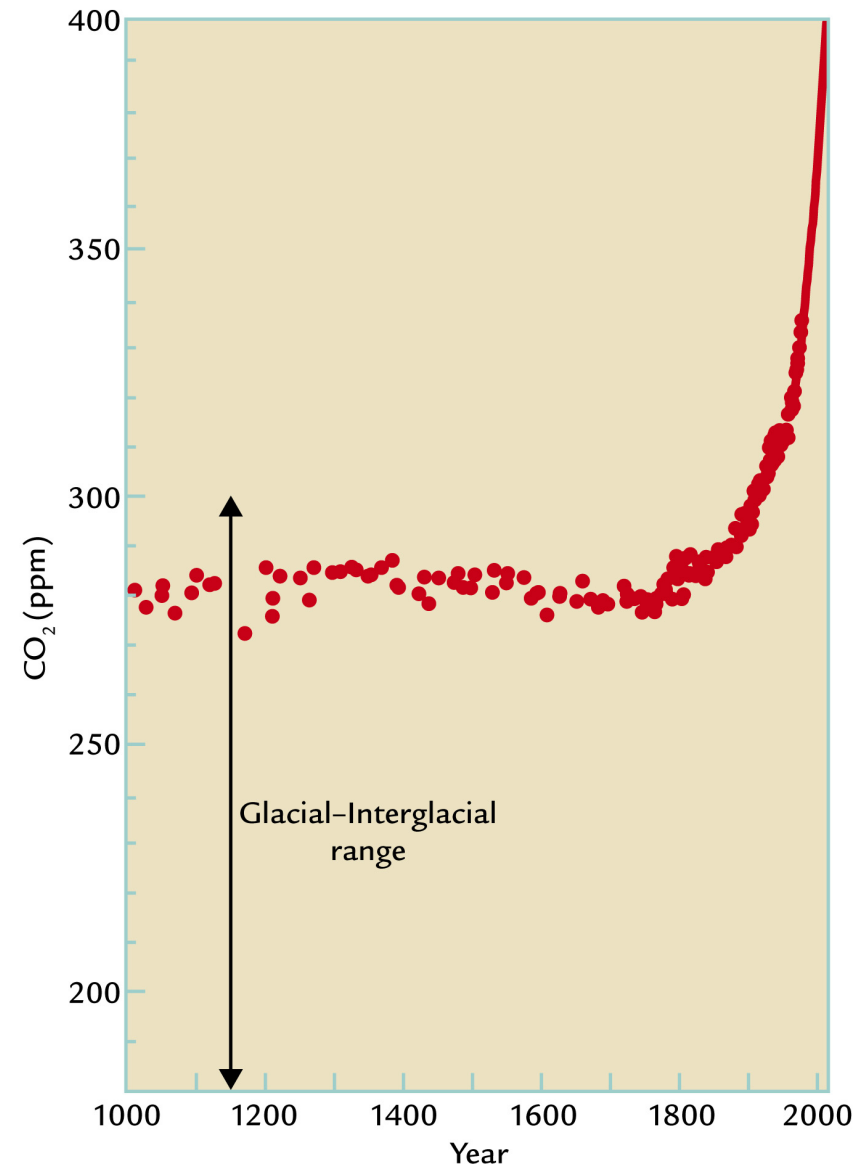


Figure from *Mann et al. (1998)*

# How does today compare to the past?

More CO<sub>2</sub> than any time in last 1000 years

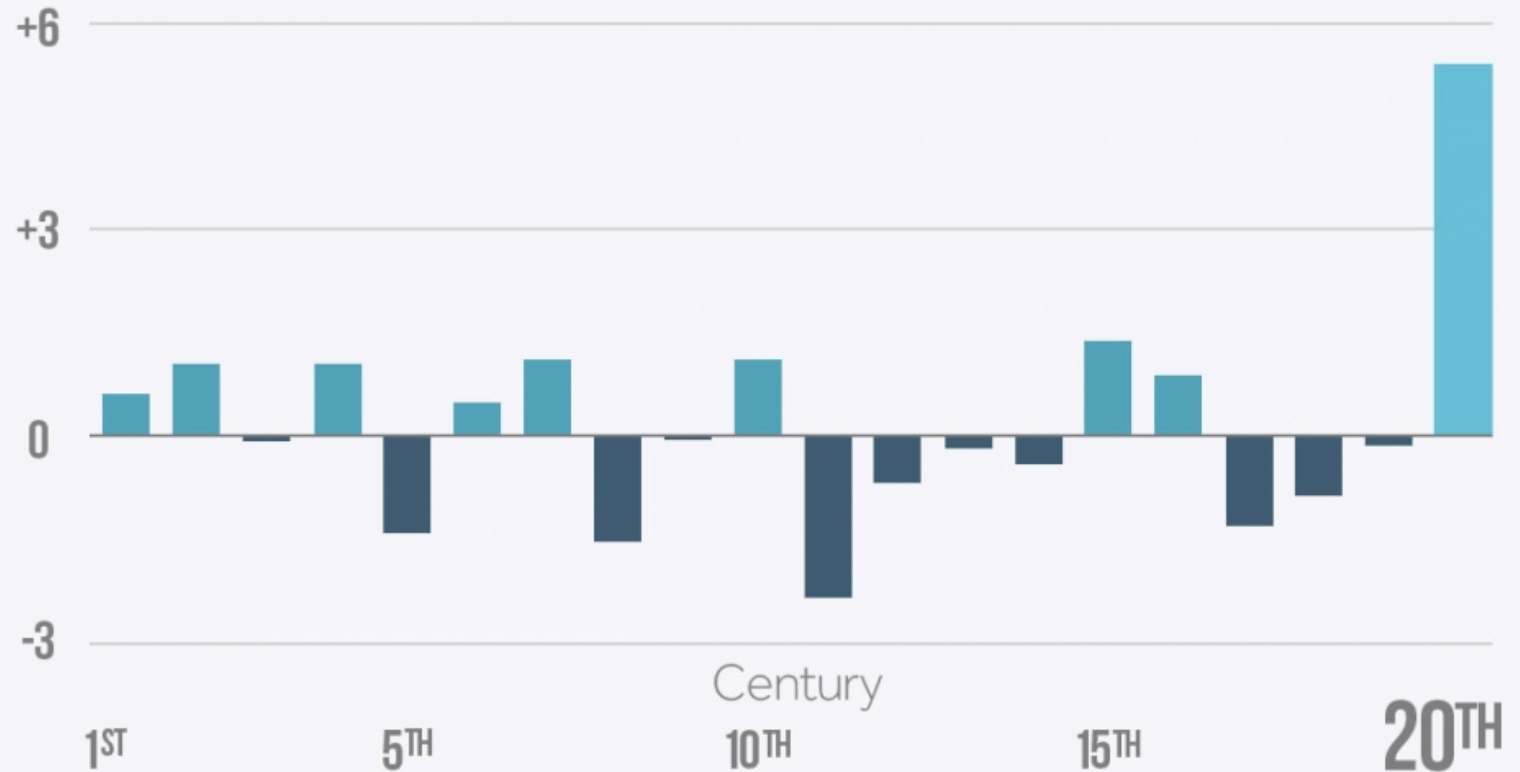


# How does today compare to the past?

More and faster  
sea level rise

## Sea Level Rise by Century

Inches:



Central reconstruction shown. Bars +/- 2 inches before 20th century  
Source: Kopp et al. 2016 (PNAS)



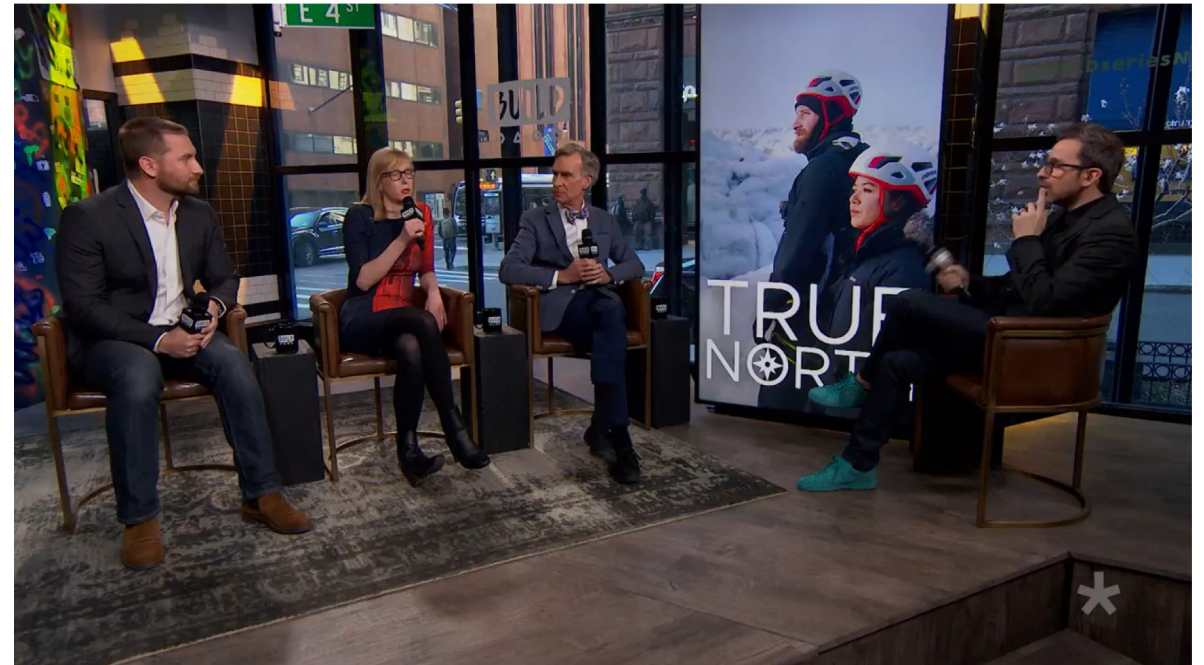
# Testing This Statement

So, global warming...

- can't be explained by natural factors,
- is occurring worldwide in the atmosphere, ocean, and on land,
- with a pattern that matches the CO<sub>2</sub> fingerprint,
- And exceeds the level of natural variability over the past 1000 years

**Human-made CO<sub>2</sub> emissions are causing global warming**

# Dr. Kate Marvel – Climate Superhero



Dr. Kate Marvel is an Associate Research Scientist at NASA GISS and Columbia University. She is a climate modeler and an active climate communicator. She writes a column for *Scientific American* (“Hot Planet”) and regularly appears on news programs to debate climate skeptics. She is **very** good at communicating climate science. Her website, [www.marvelclimate.com](http://www.marvelclimate.com), is one of the best climate science resources available