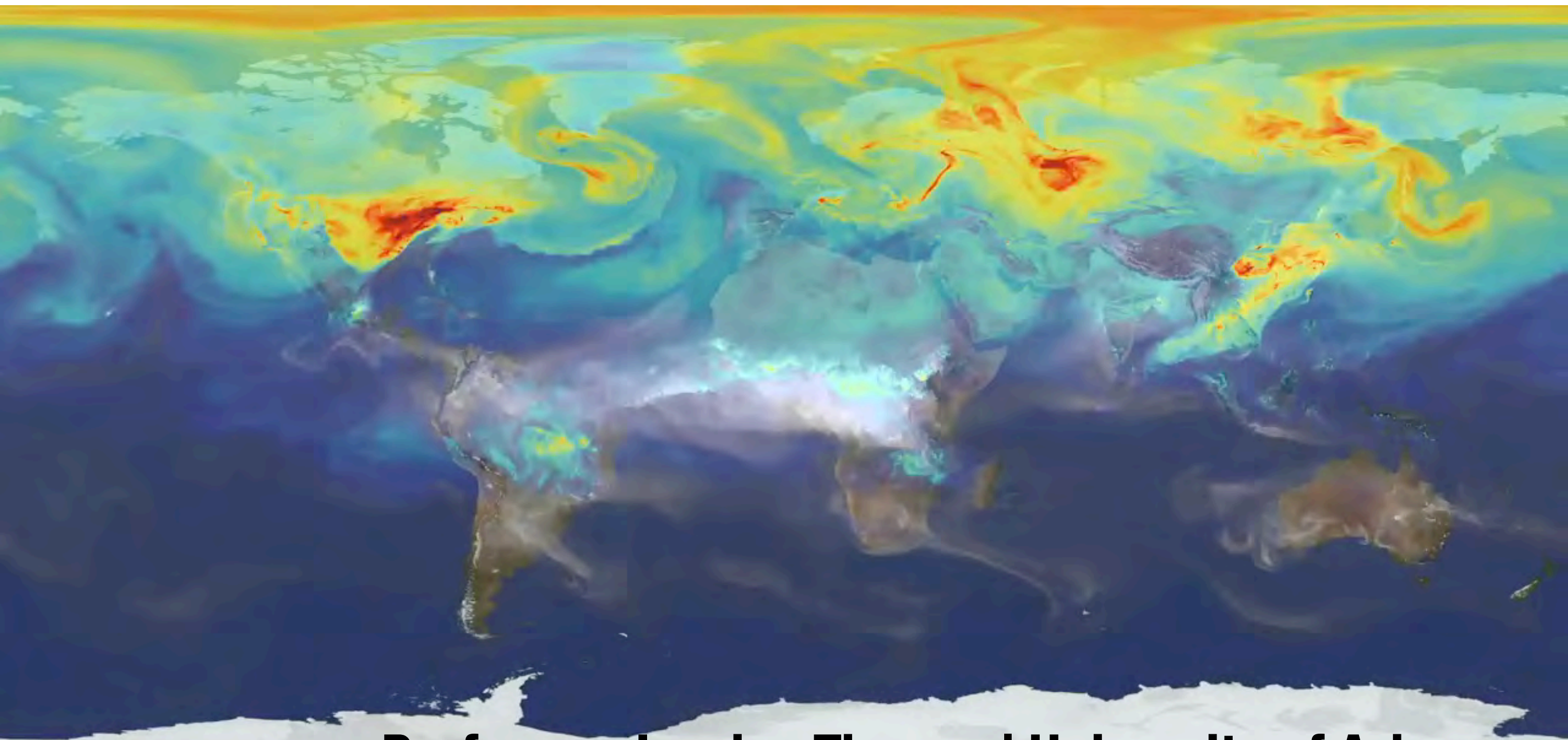


# Earth's climate trajectory

## Past, present, future



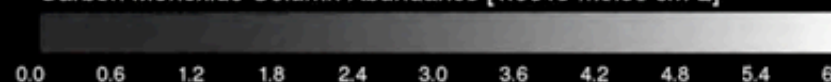
**Professor Jessica Tierney | University of Arizona**



**2006 / 01 / 01**

Global Modeling and Assimilation Office

Carbon Monoxide Column Abundance [ $1.0 \times 10^{18}$  molec  $\text{cm}^{-2}$ ]



Carbon Dioxide Column Concentration [ppmv]







**The journey towards a high  $\text{CO}_2$  future has begun.**

**The journey towards a high  
CO<sub>2</sub> future has begun.**

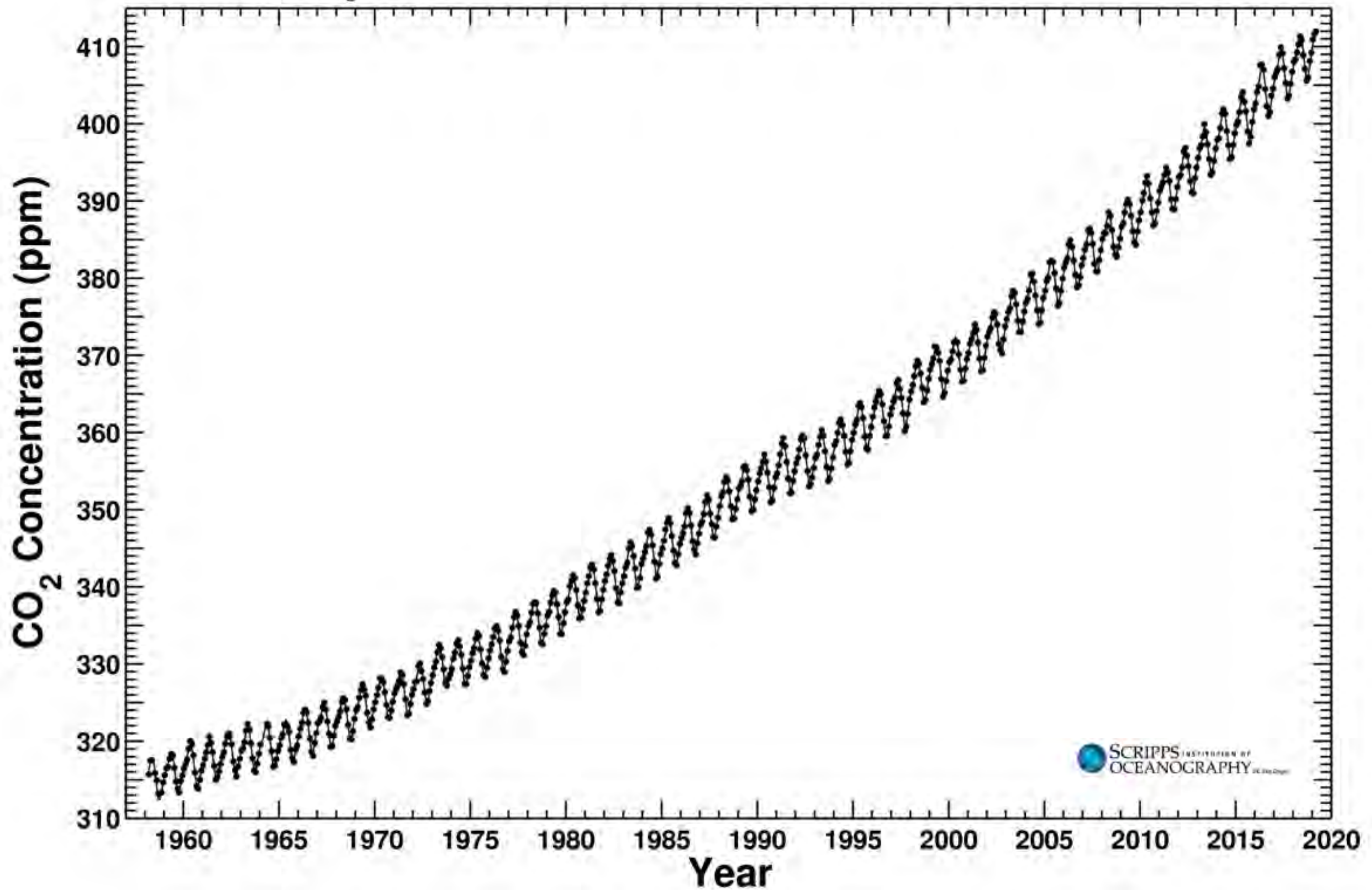




# Mauna Loa Observatory, Hawaii

## Monthly Average Carbon Dioxide Concentration

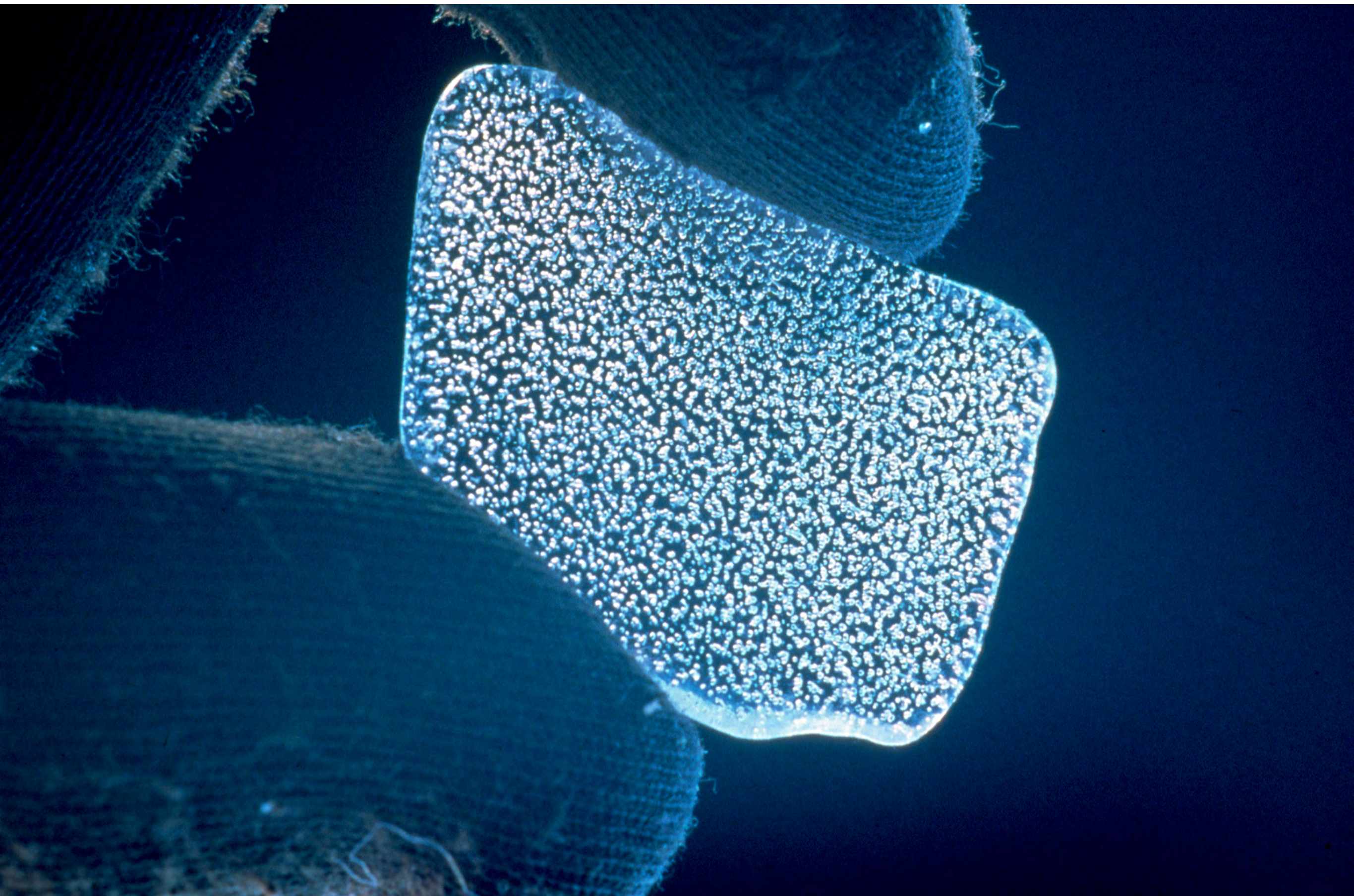
Data from Scripps CO<sub>2</sub> Program Last updated April 2019







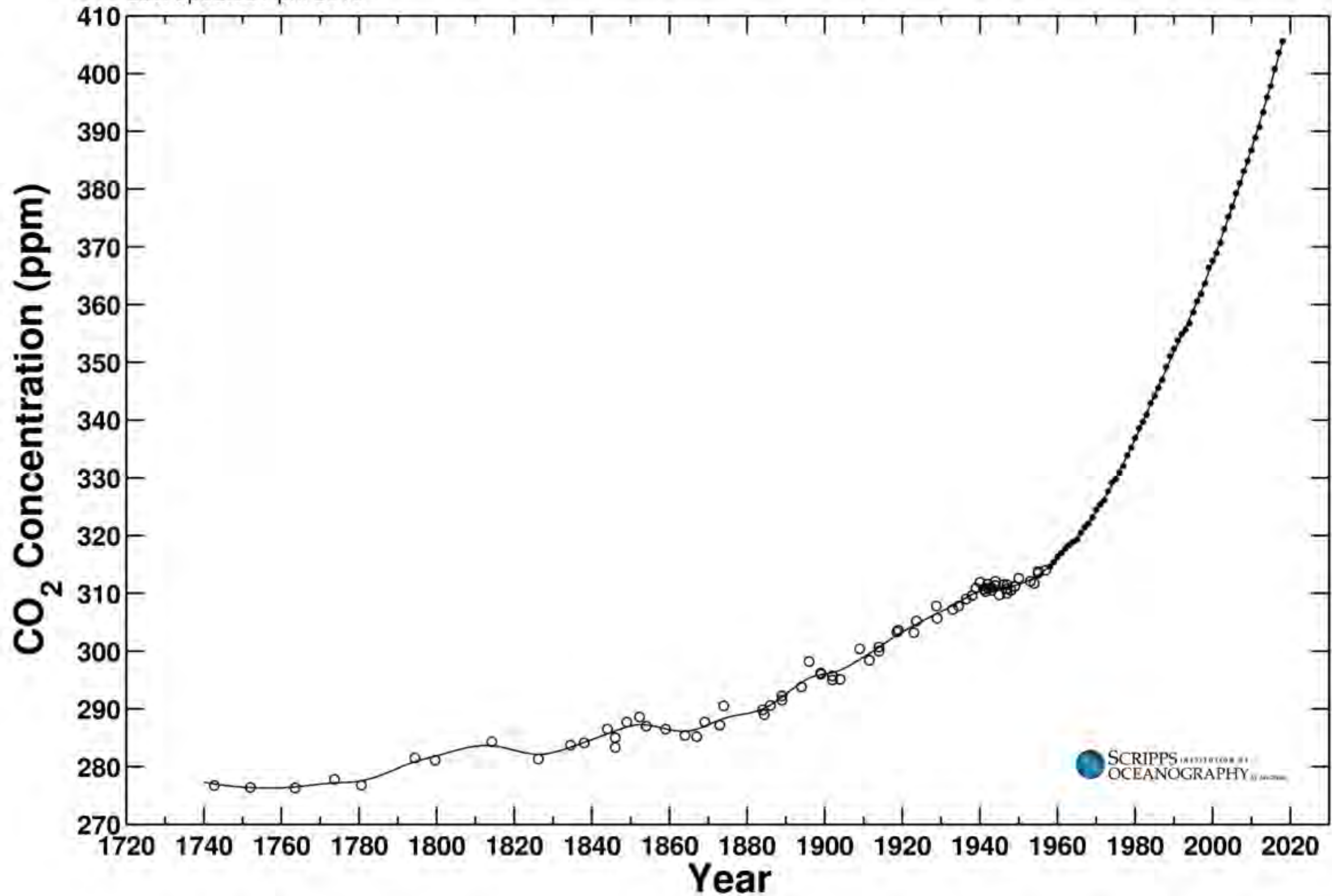




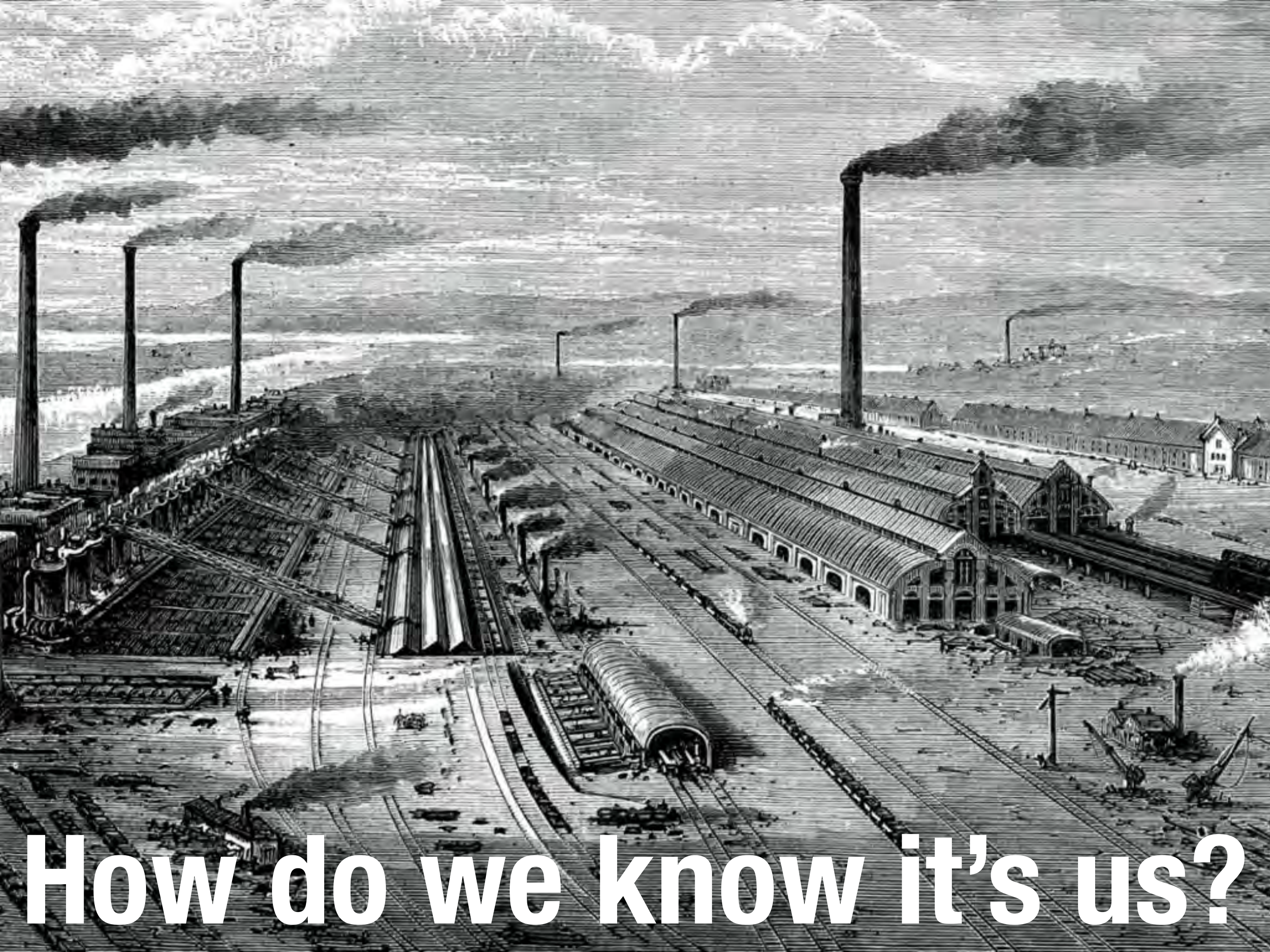


# Merged Ice-Core Record

Last updated April 2019



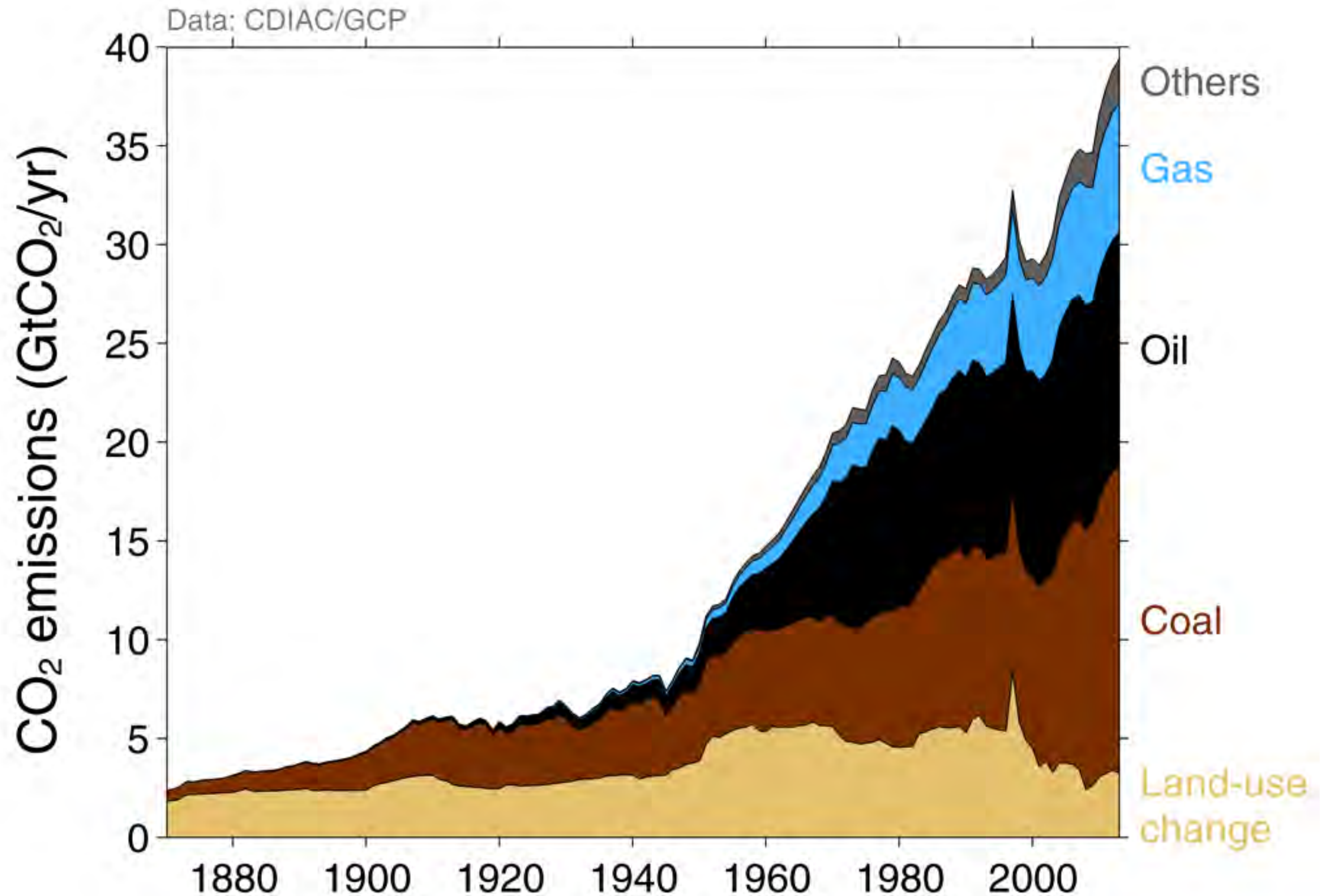




**How do we know it's us?**

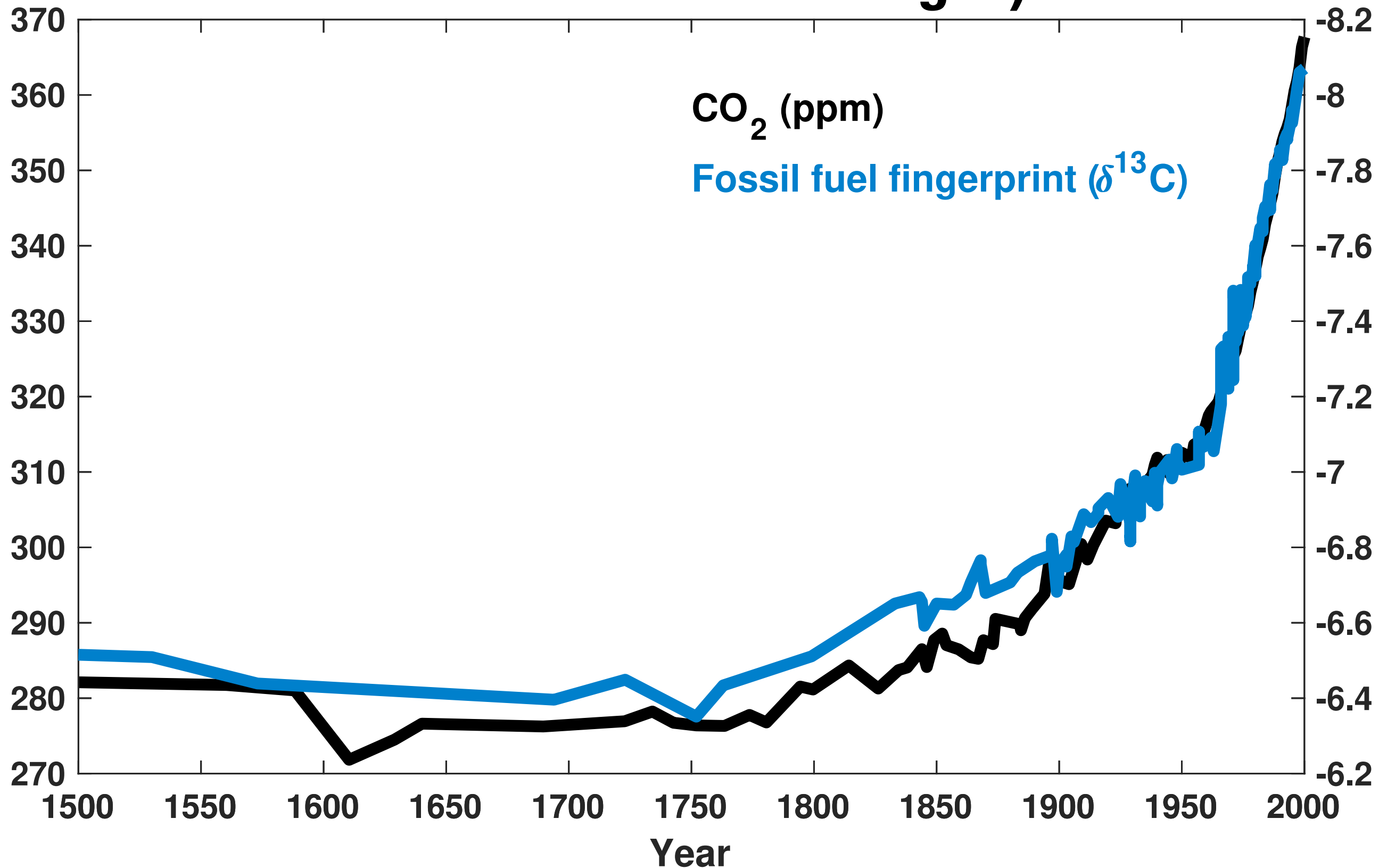


# 1) Accounting. We know how much we put out, so we know how much should end up in the atmosphere.





## 2) Chemistry. The CO<sub>2</sub> in the atmosphere is has the chemical “fingerprint” of fossil fuels (very old, made from dead trees and algae).





**Why should  
I care?**





**CO<sub>2</sub> heats things up and we have  
known that for a long time because**

# **Physics**

Joseph Fourier

1820s: First to  
propose the  
existence of the  
'greenhouse  
effect'





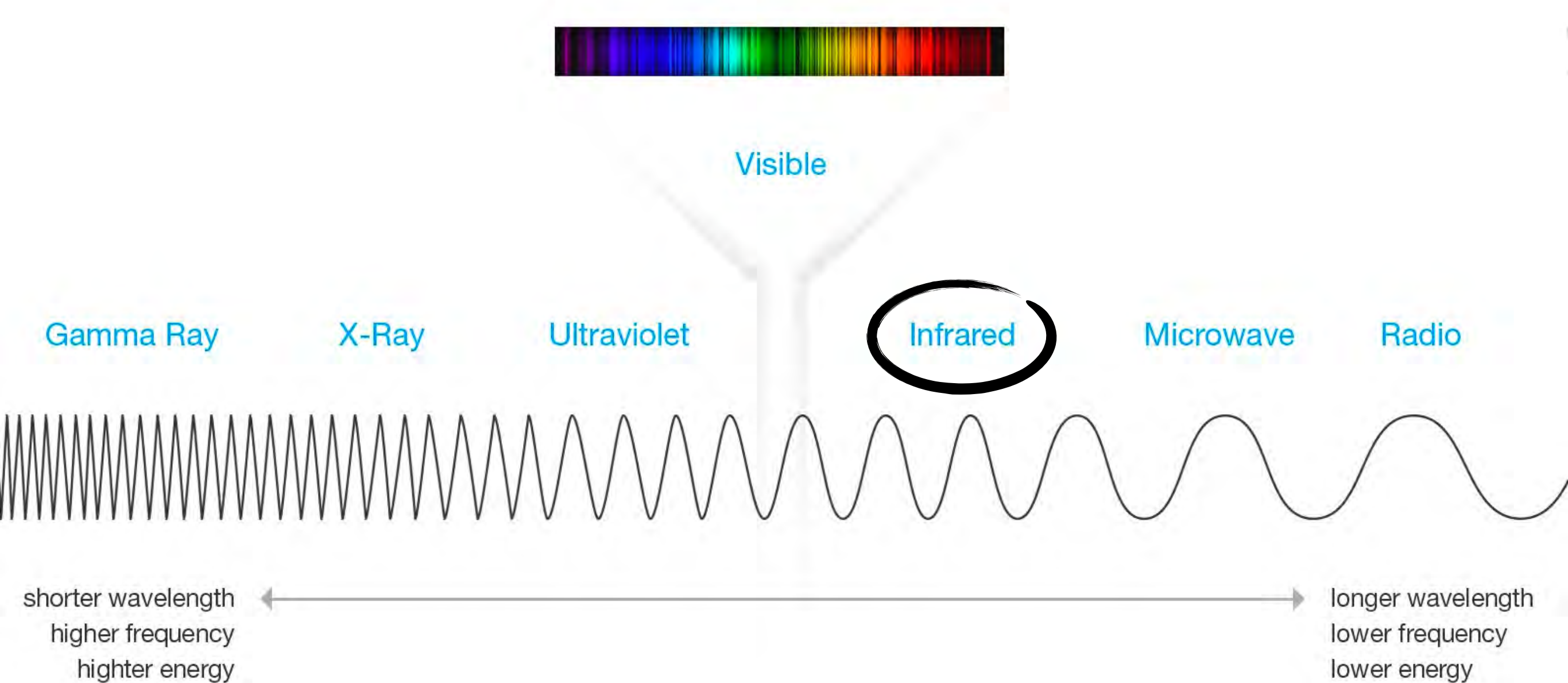
'Vibrations in a gas molecule are like vibrations of a piano string in that they are fussy about frequency. This is because, like a piano string, a gas molecule will only vibrate at its "ringing" frequency'





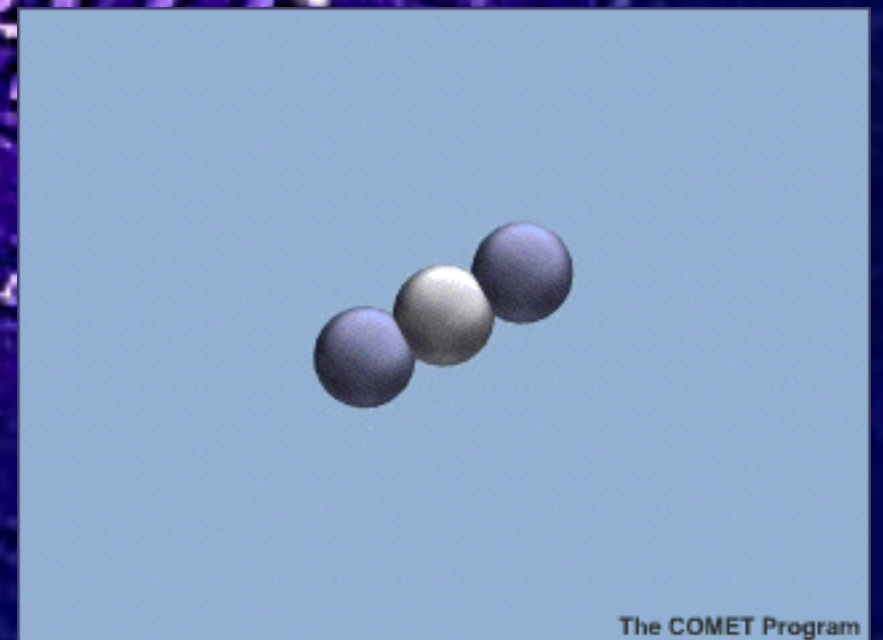
# The spectrum of energy

## (Electromagnetic spectrum)

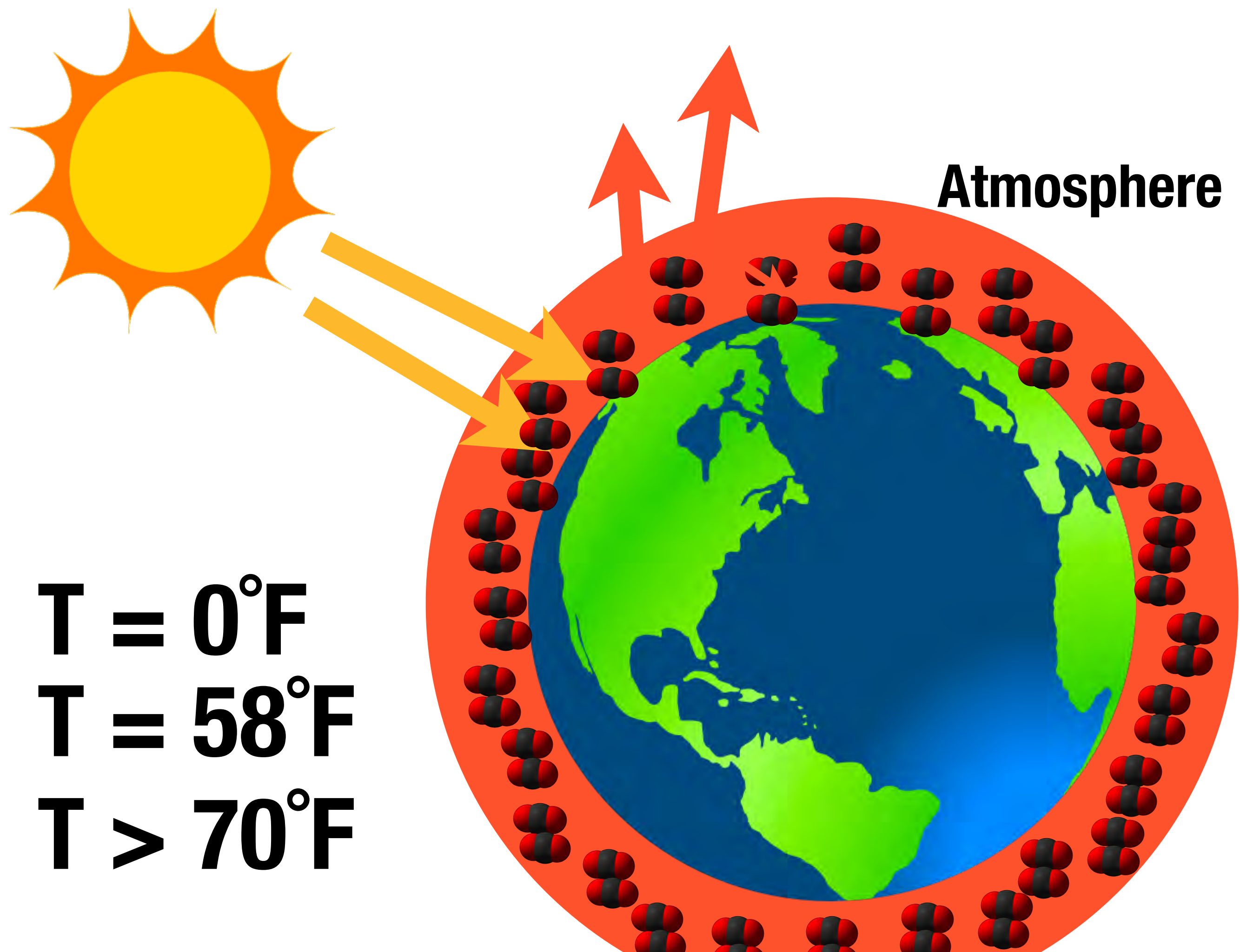




**CO<sub>2</sub>**  
**vibrates**  
**with the**  
**infrared**



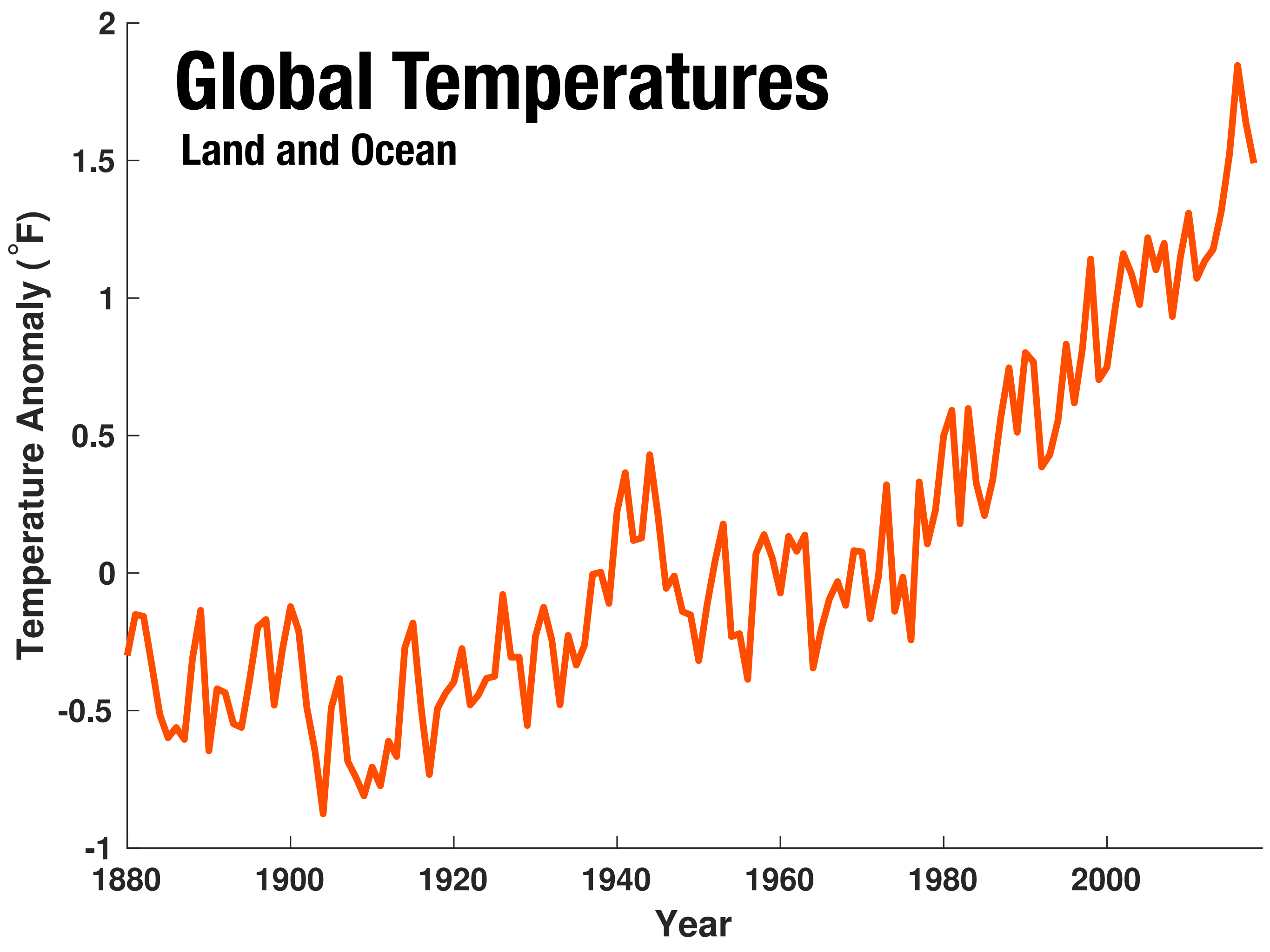






# Global Temperatures

Land and Ocean





**Carroll Glacier, Alaska. 1906**

**It's Real**



**2004.**





# It's Real



## High tide in Miami Beach, FL



# It's Real



## Extreme drought in California, 2015



**Where are we headed?**

**What  
should we  
expect?**





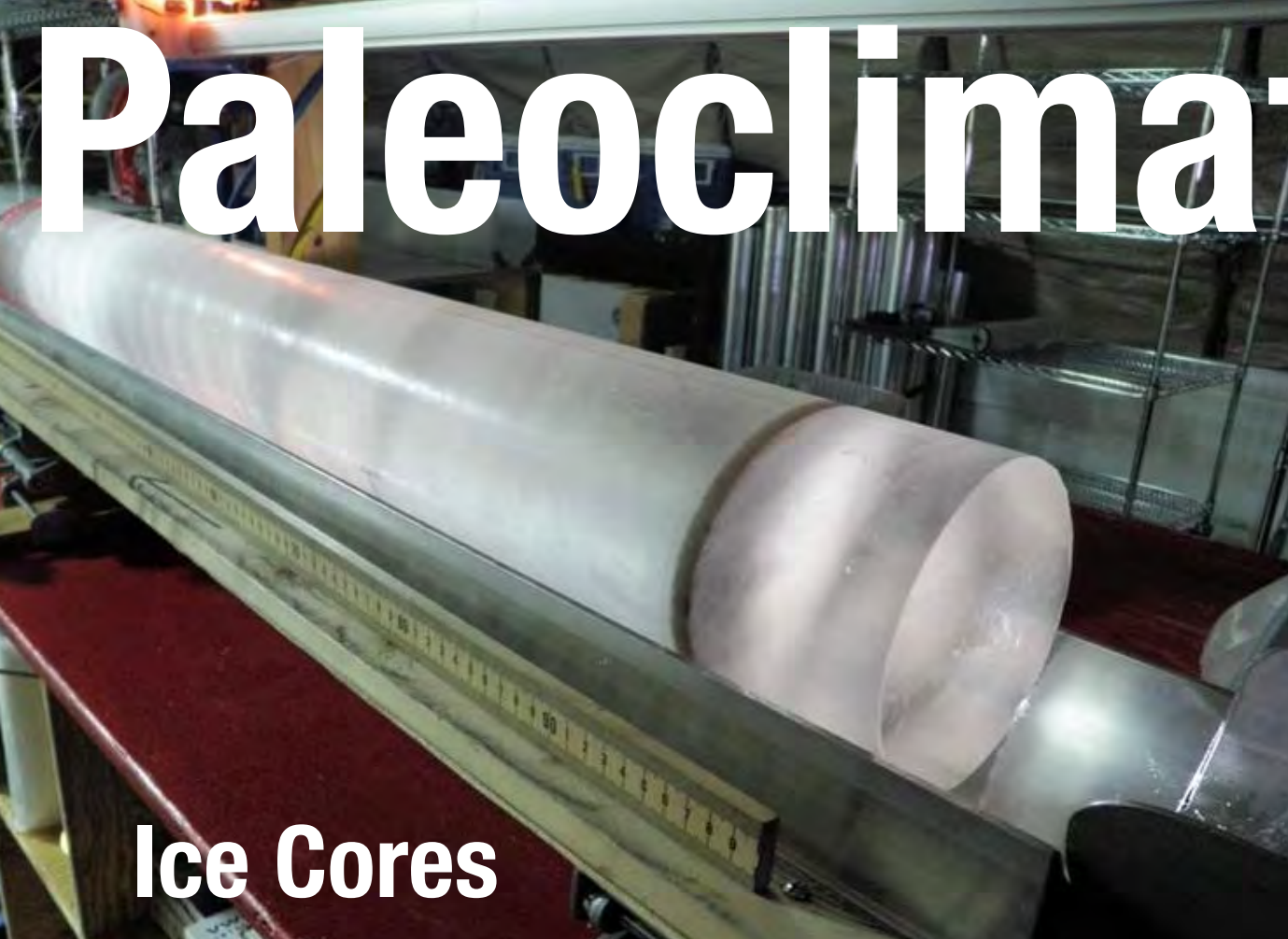


**Trying to understand climate change by observing just the last few decades is like trying to understand the rules of the game by watching just a few plays**





# Paleoclimate archives



**Ice Cores**



**Tree Rings**



**Stalagmites**

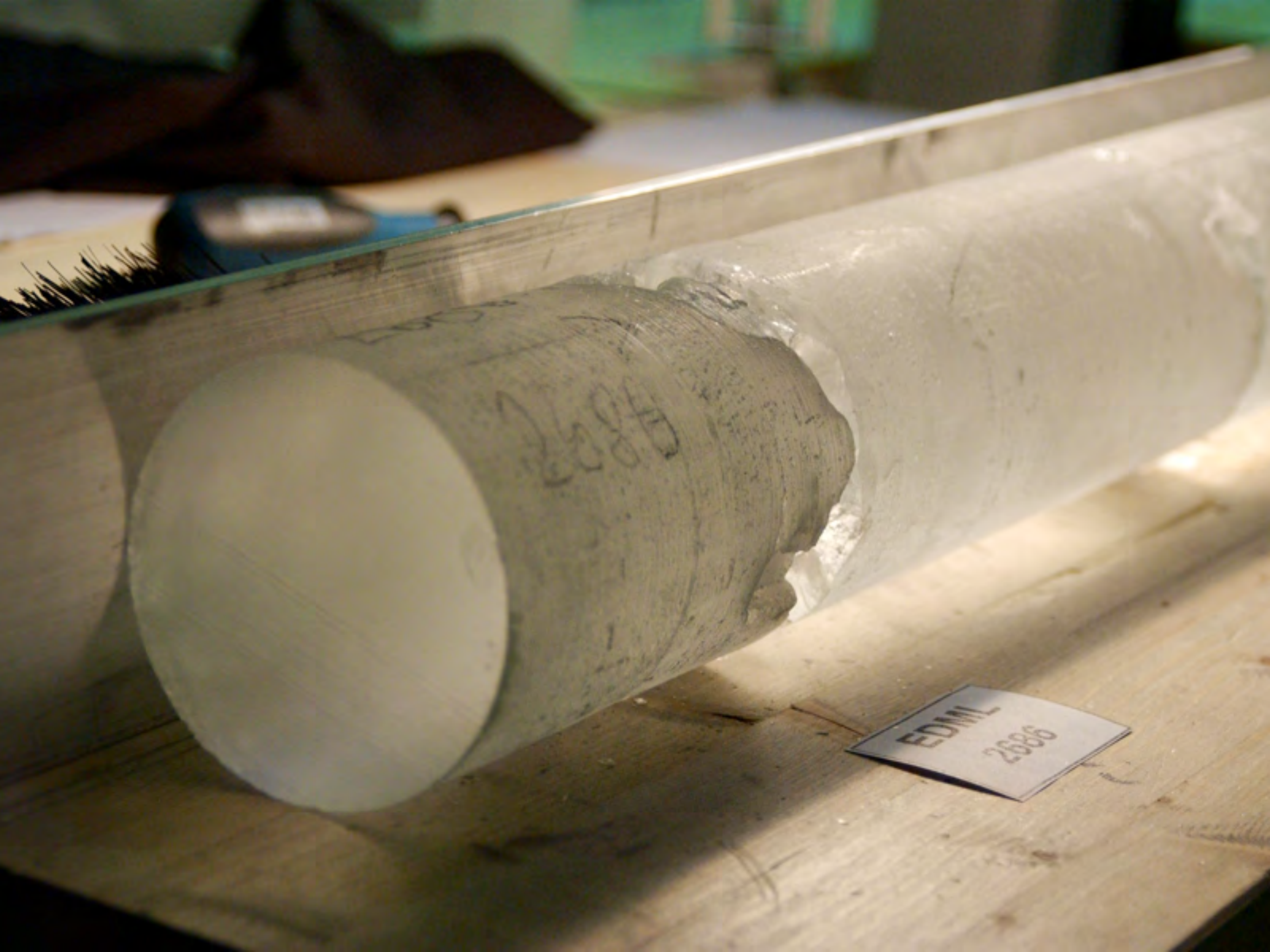


**Sediments**



**Corals**

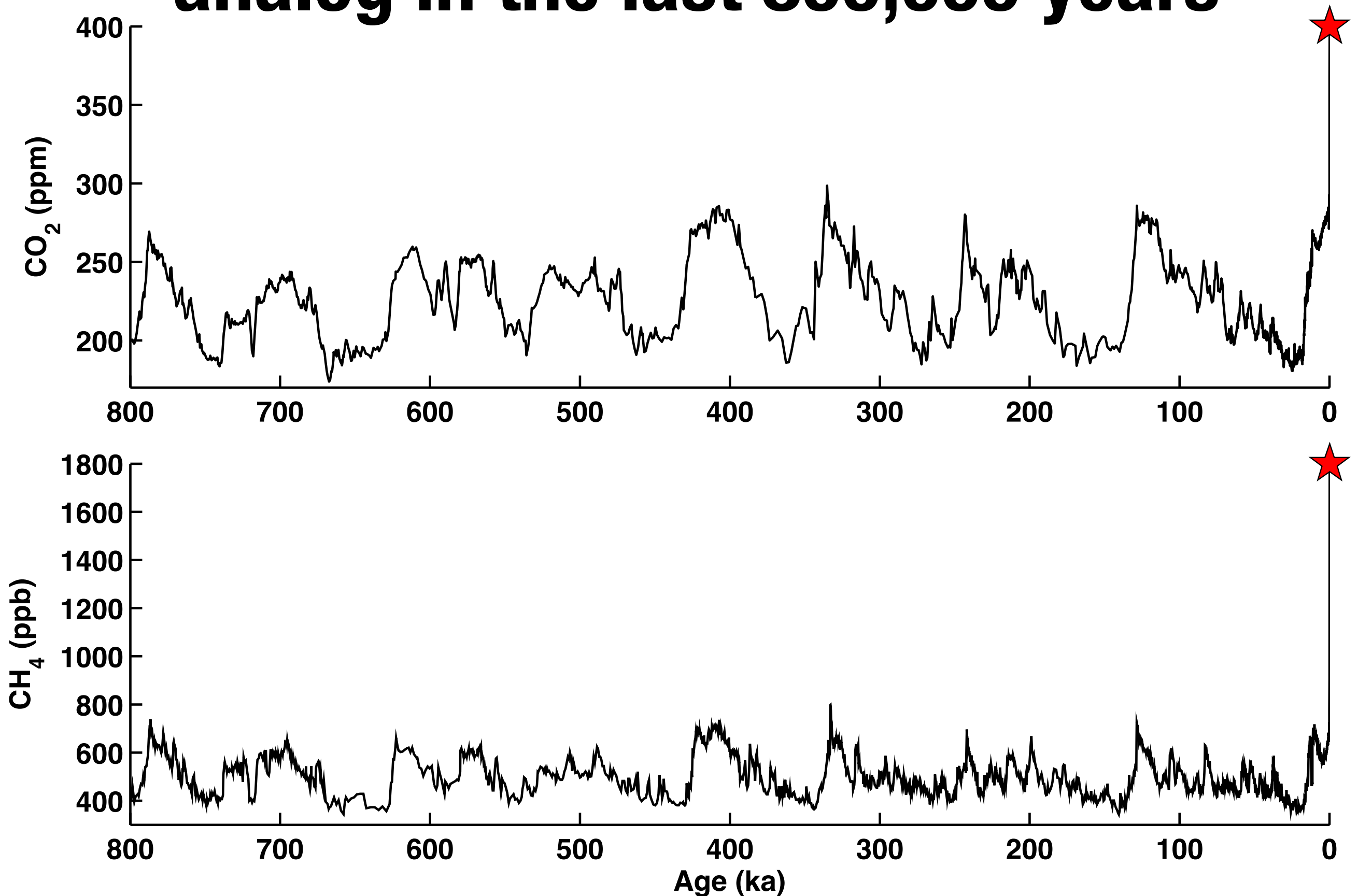




EDMIL  
2686



# Current GHG concentrations have no analog in the last 800,000 years

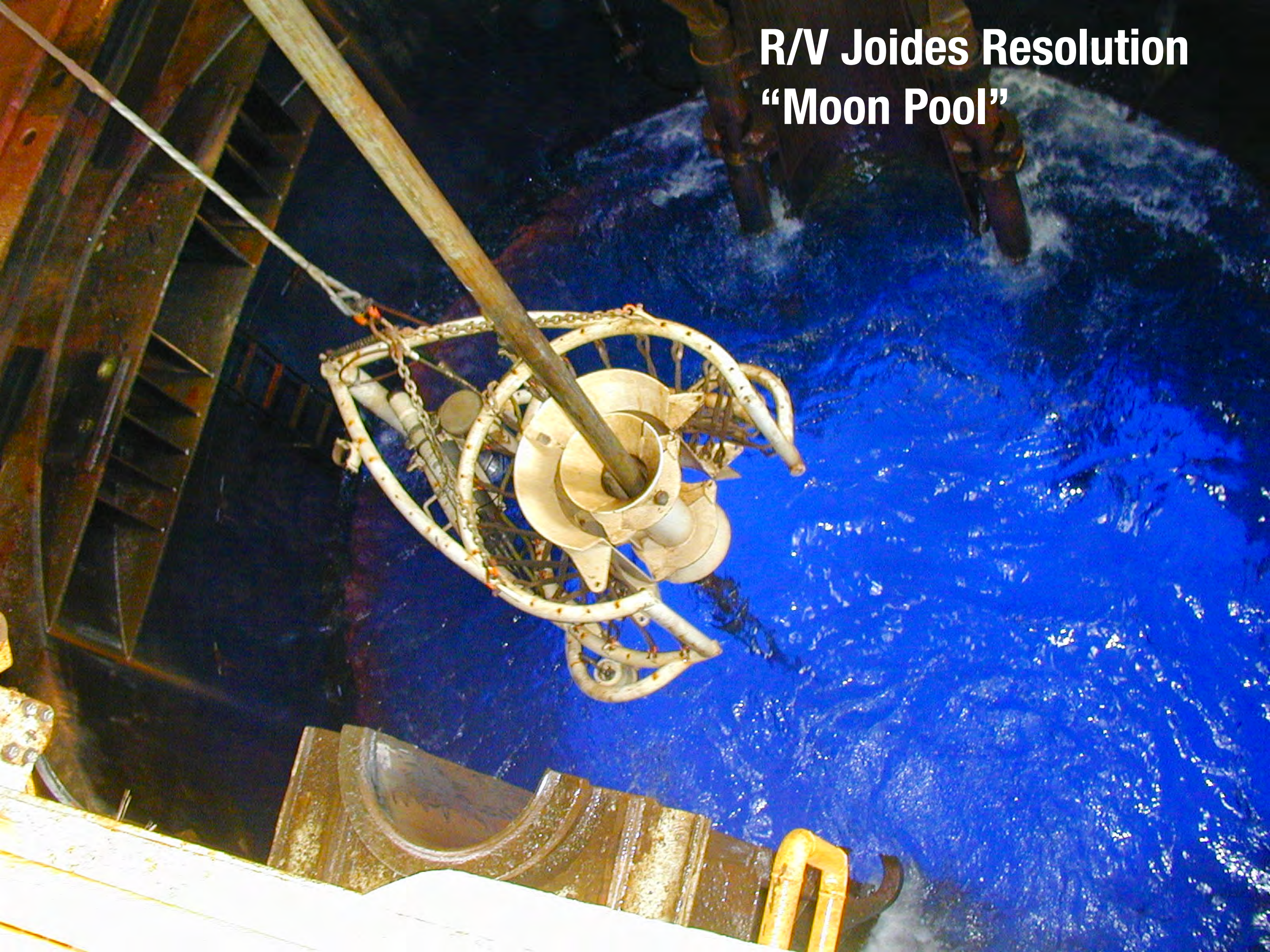








# R/V Joides Resolution “Moon Pool”

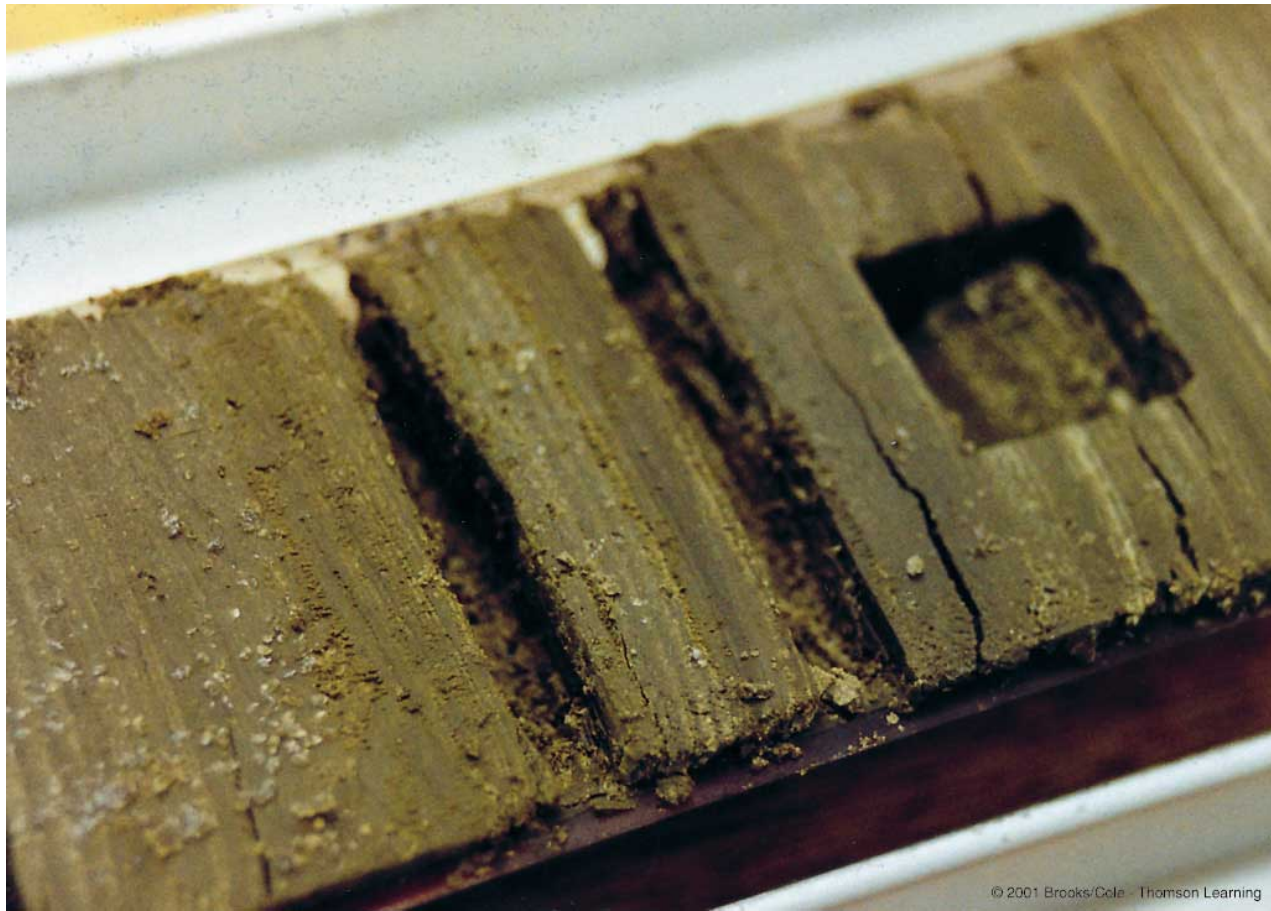








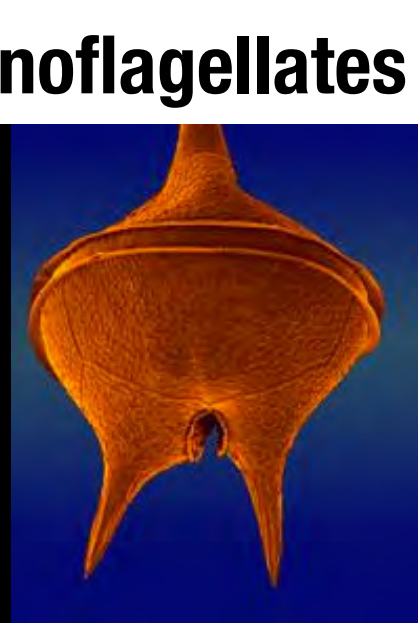
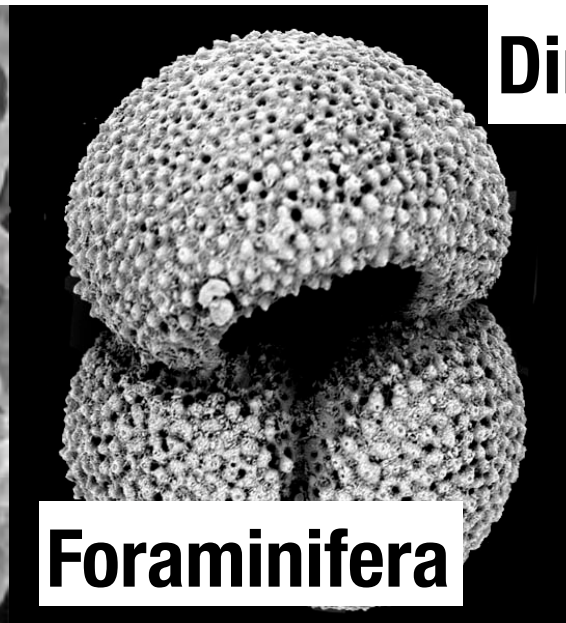
# Core Sampling



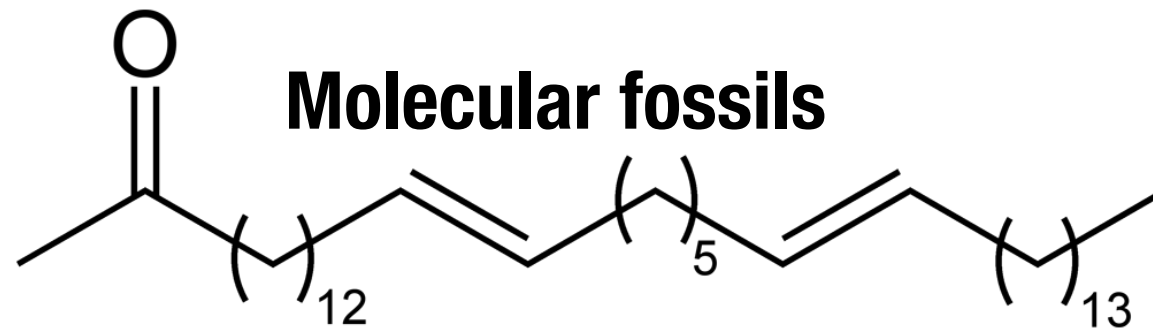


# Stuff you can measure in mud

## Microfossils



$^{230}\text{Th}_{\text{xs}}$   
isotopes

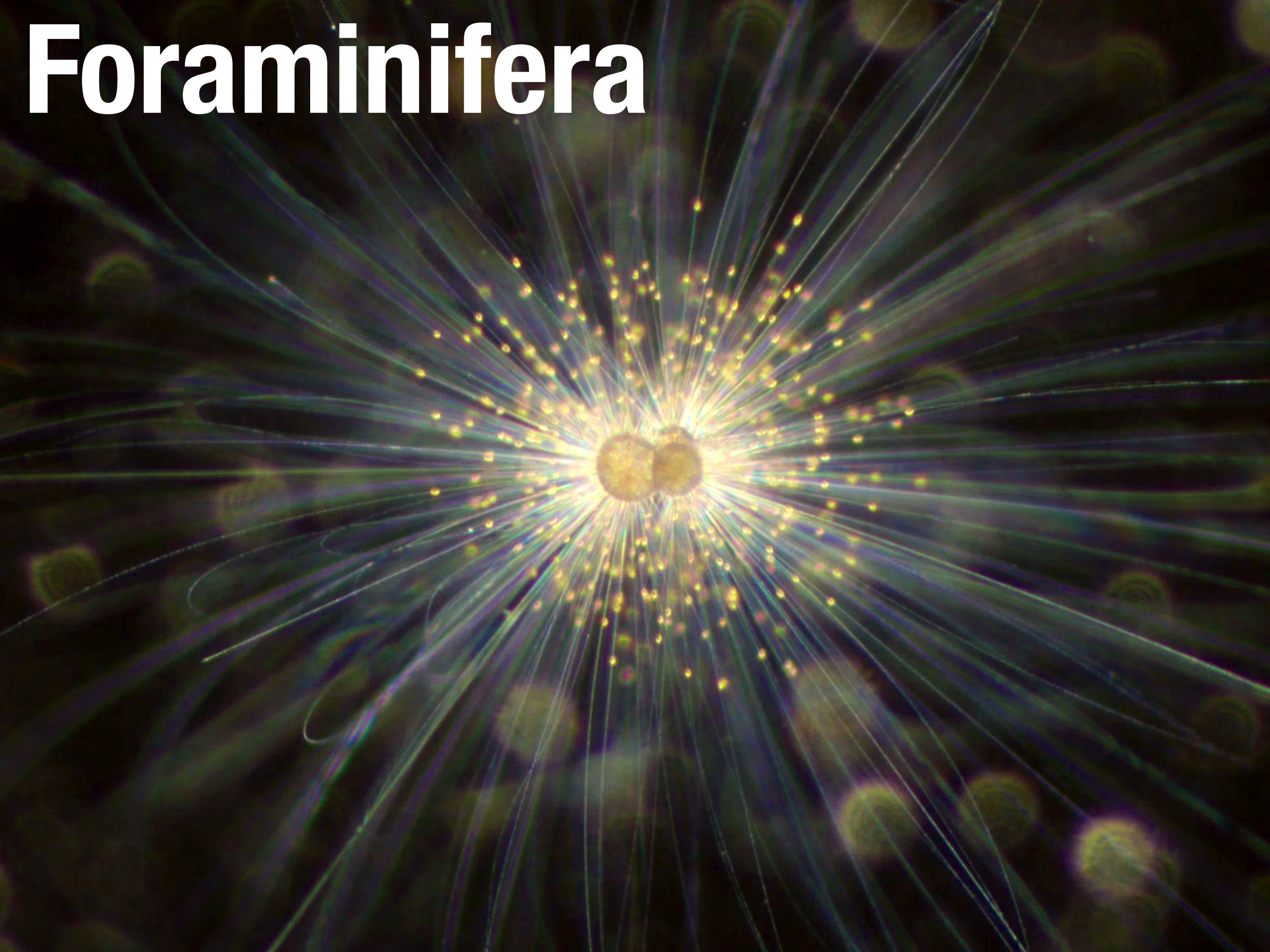


**Chemical  
properties**

**Physical  
properties**







# Foraminifera

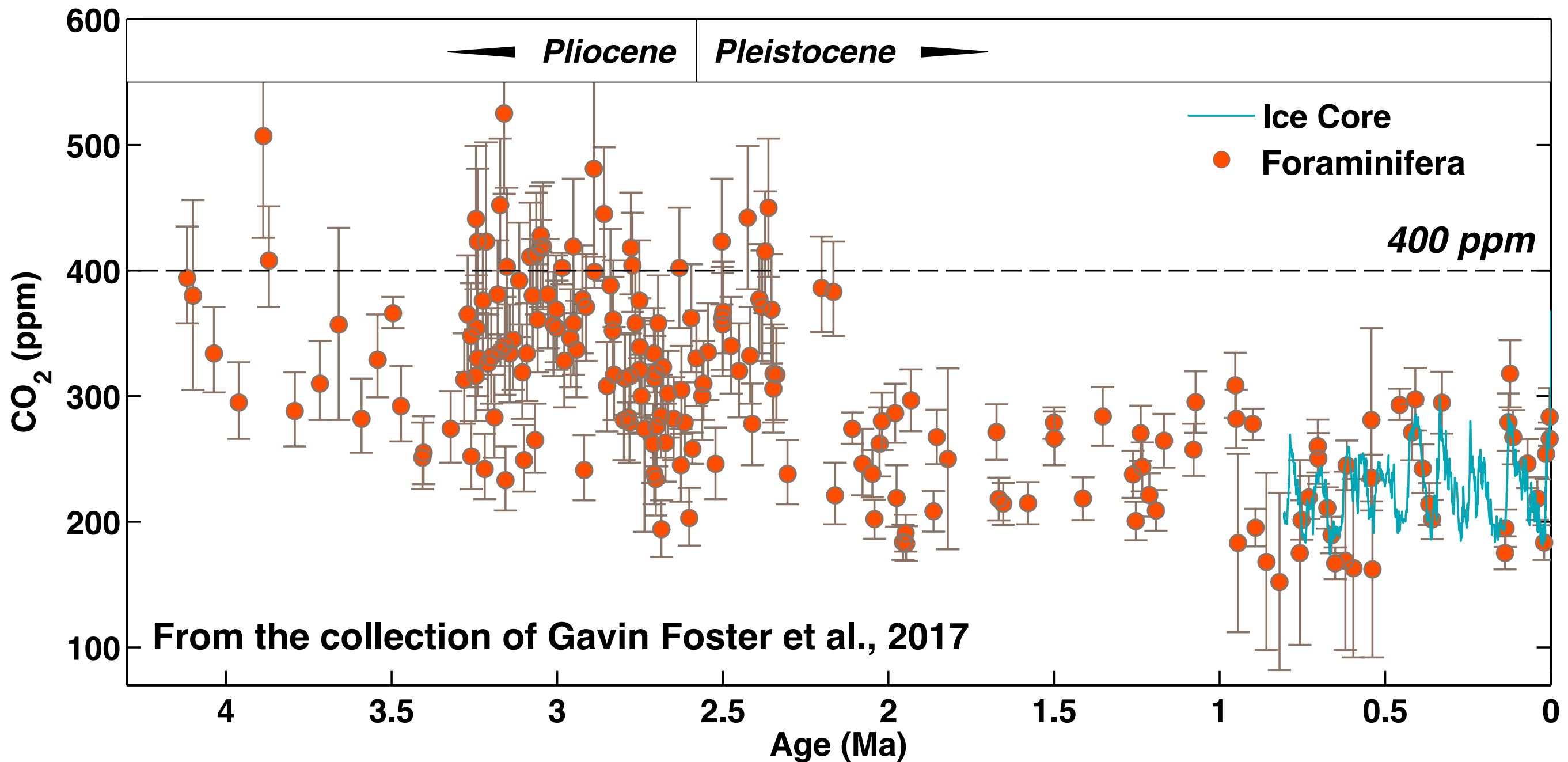






Chemical measurements in foraminifera tell us...

The last time CO<sub>2</sub> was this high  
was 2.5 million years ago.

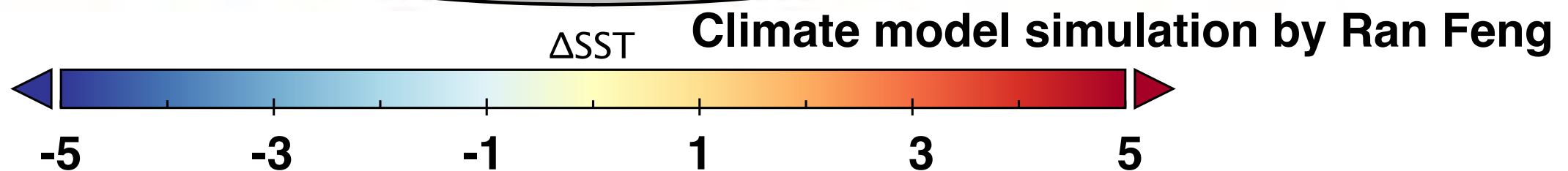
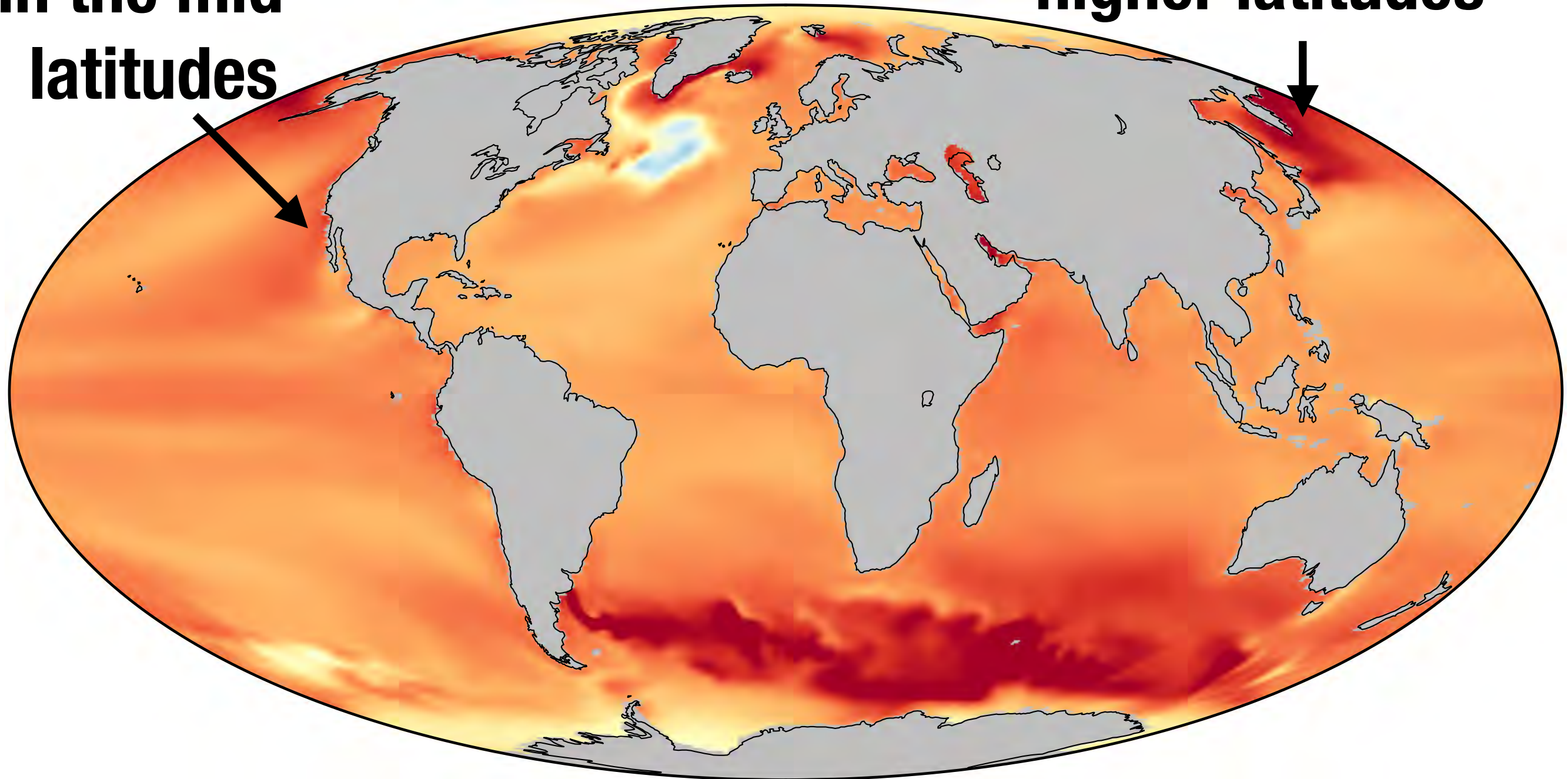




# Welcome to the Pliocene

**3°F warmer  
in the mid-  
latitudes**

**7°F warmer in the  
higher latitudes**





# (Almost no) Greenland Ice Sheet

**Today**



**Pliocene**

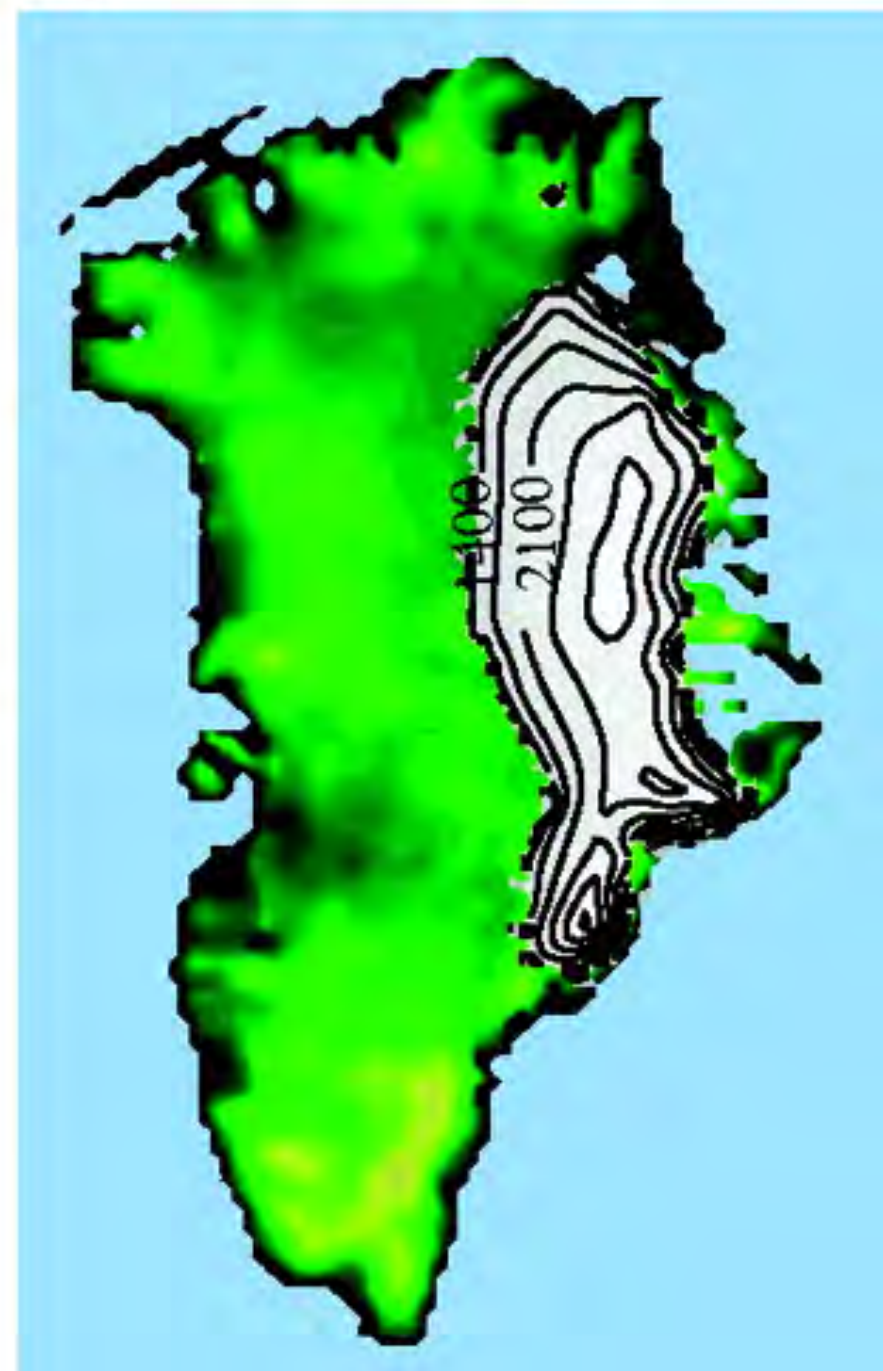


Figure from Dan Lunt et al., 2009





**We had  
not  
evolved  
yet.**

**Lucy, the Australopithecus**



# **(We are an ice age species)**

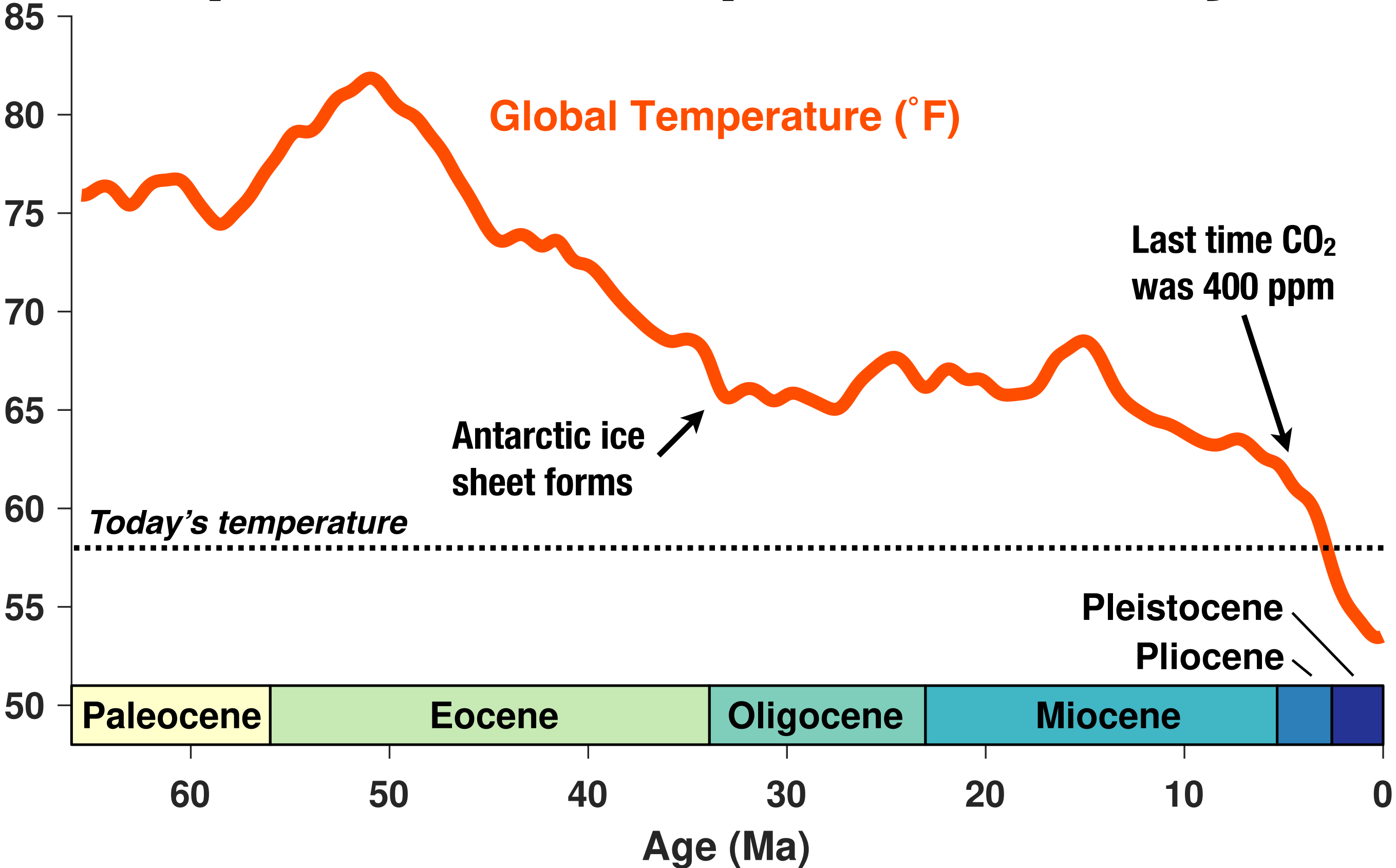
**Homo sapiens evolved 200,000 years ago**





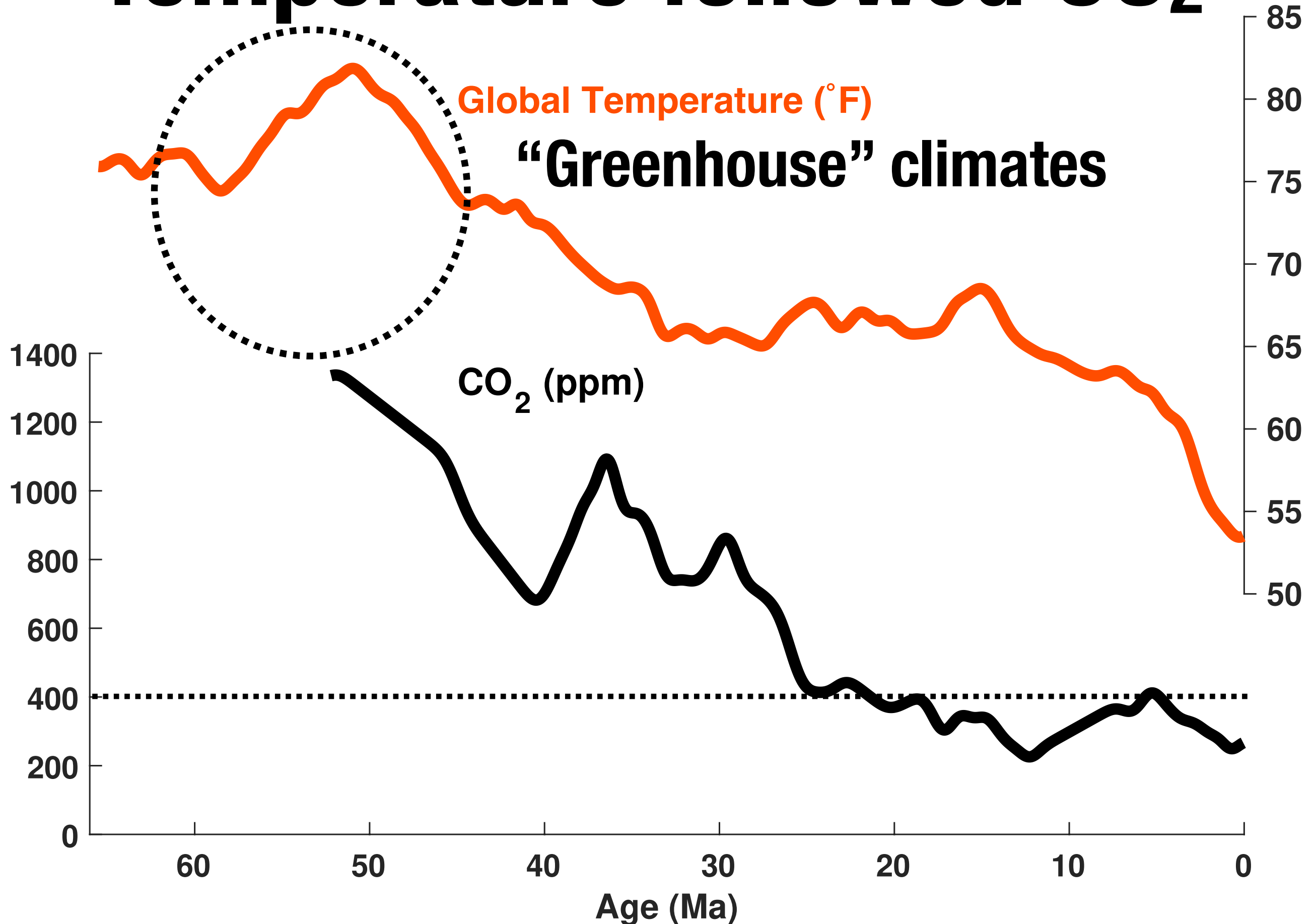
# Chemical measurements in foraminifera tell us...

## Temperature for the past 65 million years





# Temperature followed CO<sub>2</sub>





# What are “greenhouse climates” like?



**Titanoboa vertebra**



**Boa constrictor vertebra**

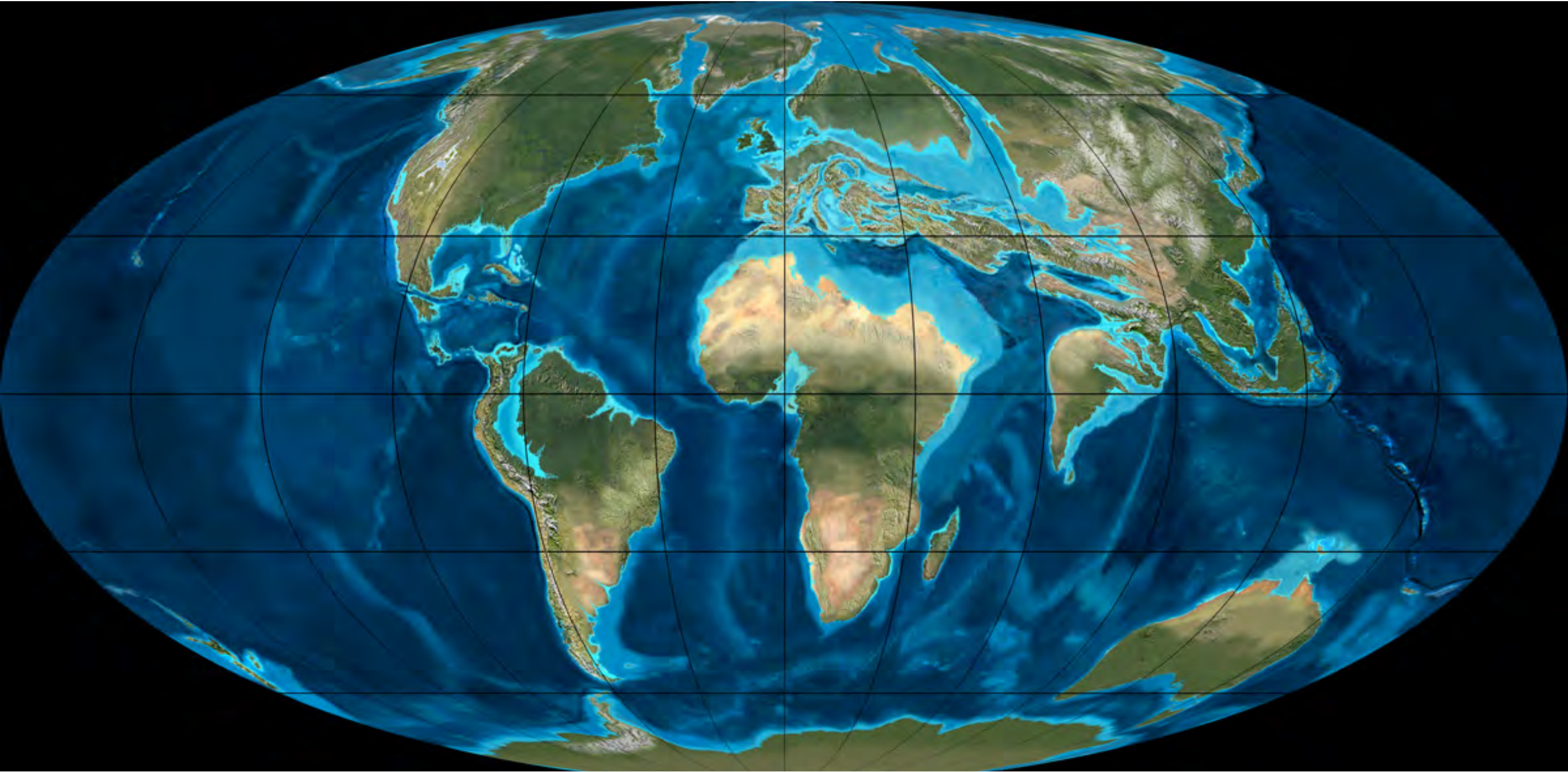


TITANOBOA

www.THE STOMPING LAND.com



# **Welcome to the Eocene**



**56-34 million years ago. CO<sub>2</sub> near 1000 ppm. No polar ice.  
The climate was steamy...**



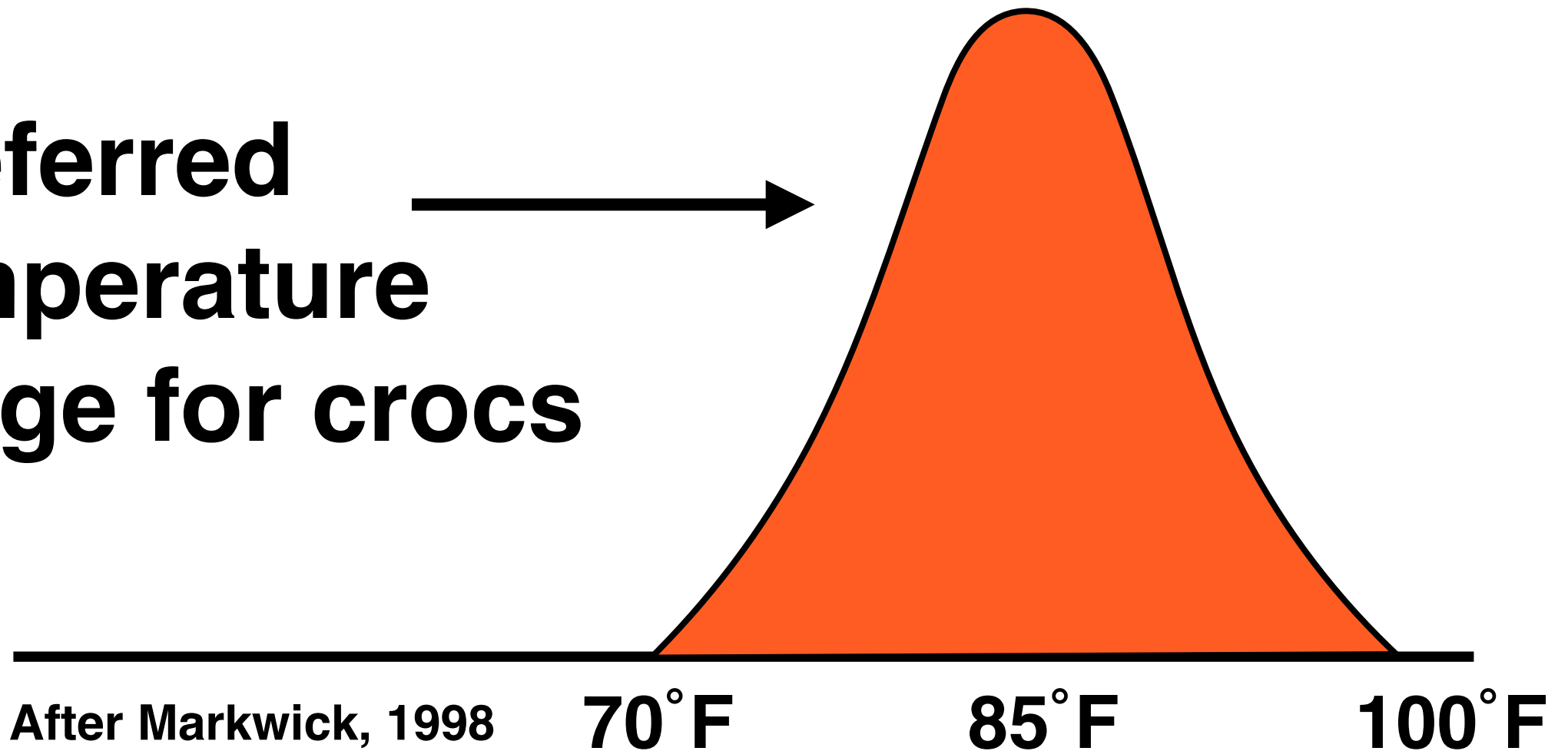






**Crocs lived in  
the Arctic!**

**Preferred  
temperature  
range for crocs**





# Palms and baobab grew in Antarctica

**Palm**



**Baobab**

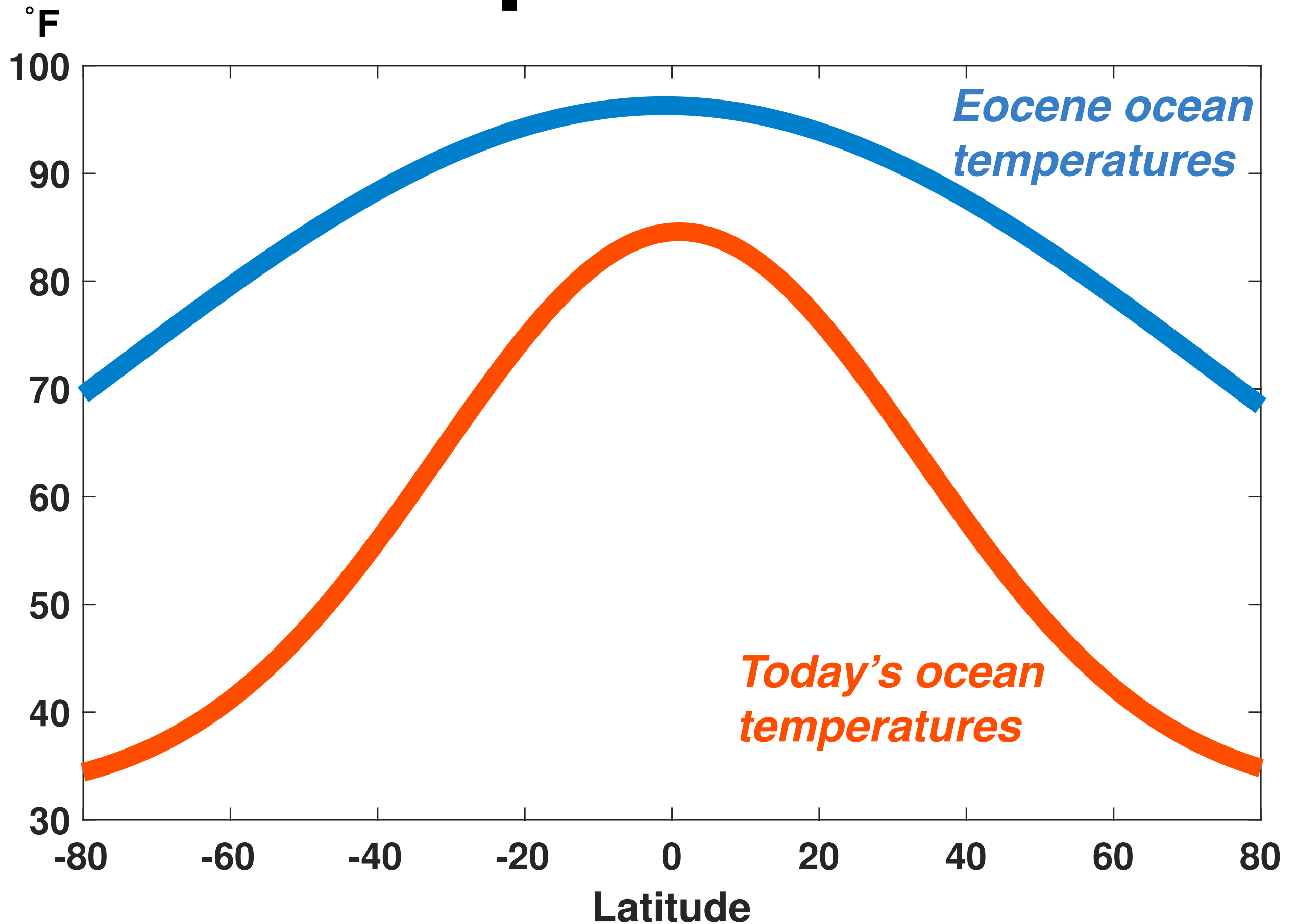


**Pross et al., 2012**



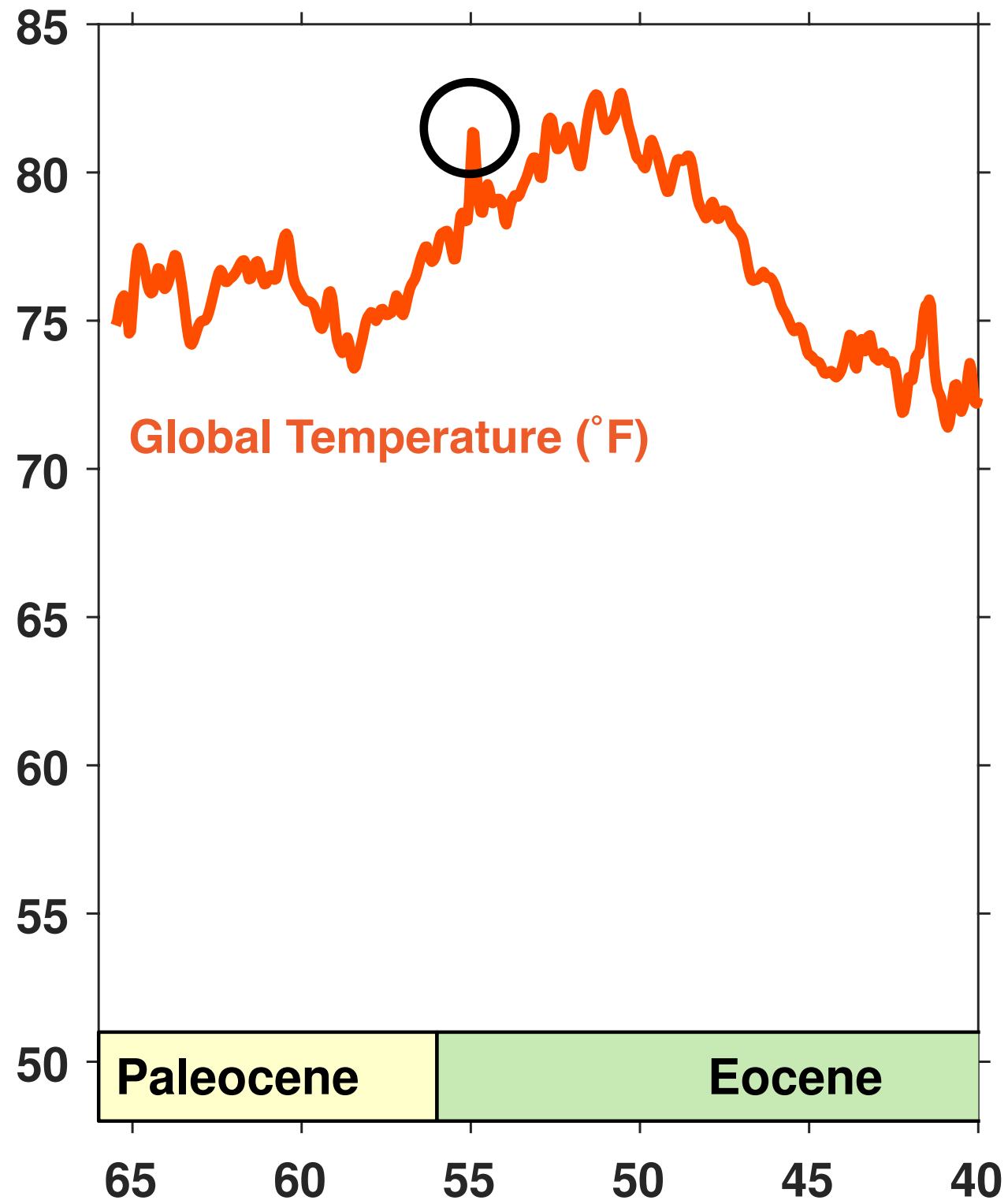


# A more “equable” climate...





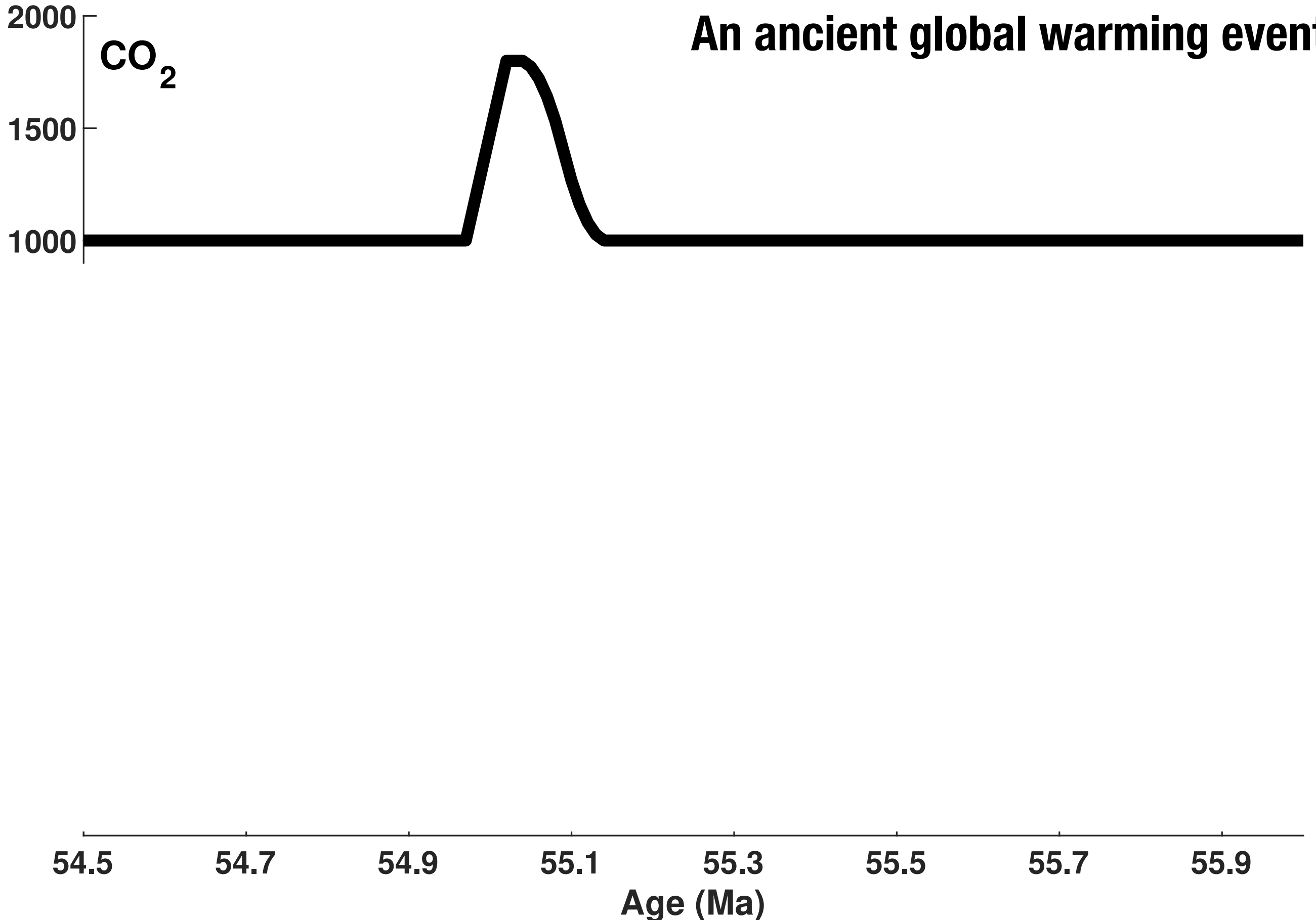
# But not a stable climate...





# The Paleocene-Eocene Thermal Maximum

An ancient global warming event.









# The PETM: evidence in sediments

**This is a deep sea sediment core taken from the South Atlantic...**

**Time** 



**Before  
PETM:  
sediments  
rich in  
carbonate**

**10,000s yrs later:  
Red clay is  
deposited...no  
carbonate, ocean is  
still acidic.**

**100,000s yrs later:  
Calcareous  
sediments return =  
ocean recovers**

**Sharp boundary = PETM.  
Ocean acidifies, seafloor  
carbonate dissolves**



# Where did the CO<sub>2</sub> come from??



Sudden methane clathrate release?

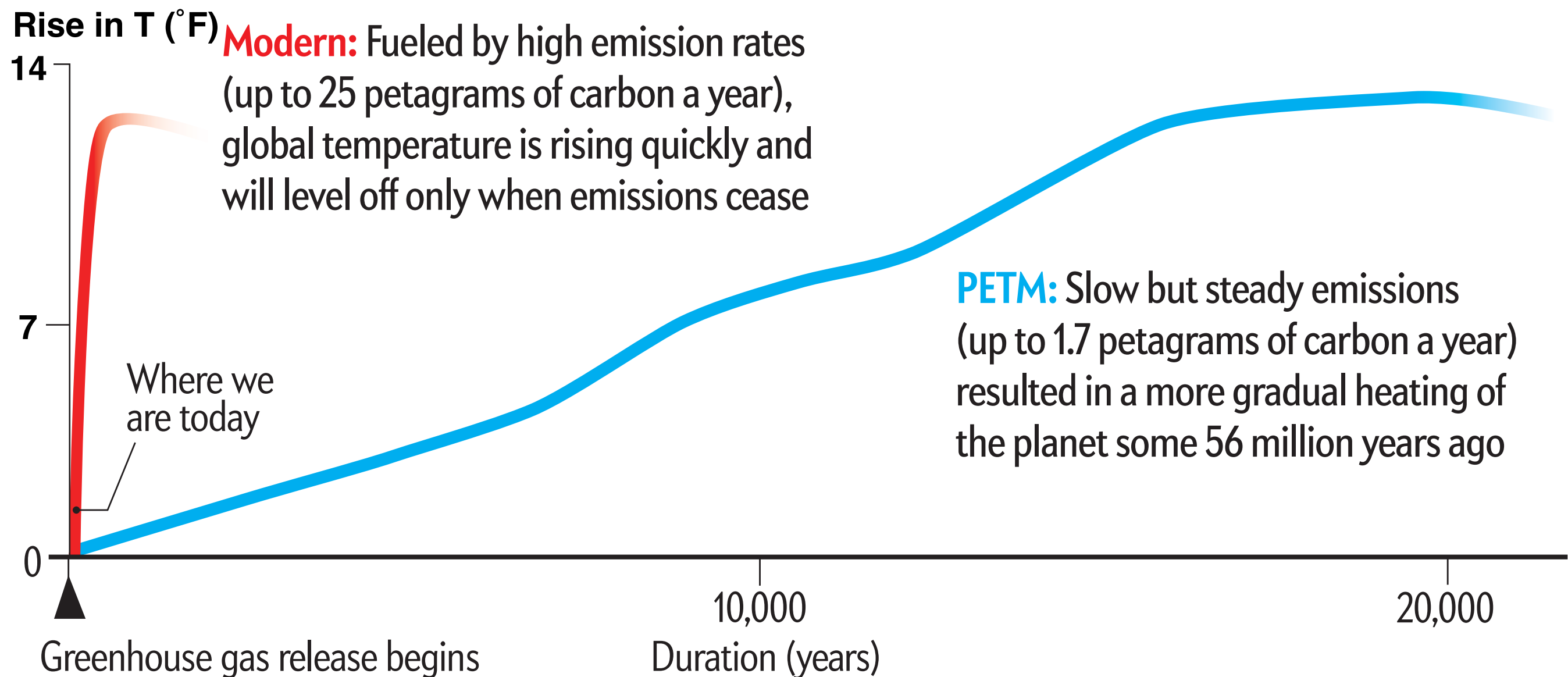
Did volcanism start it off?



Maybe melting permafrost?



# The PETM tells us about how the Earth handles a rapid rise in CO<sub>2</sub>. Except, the CO<sub>2</sub> rise happening now is way faster than the PETM.





**It's Real.**

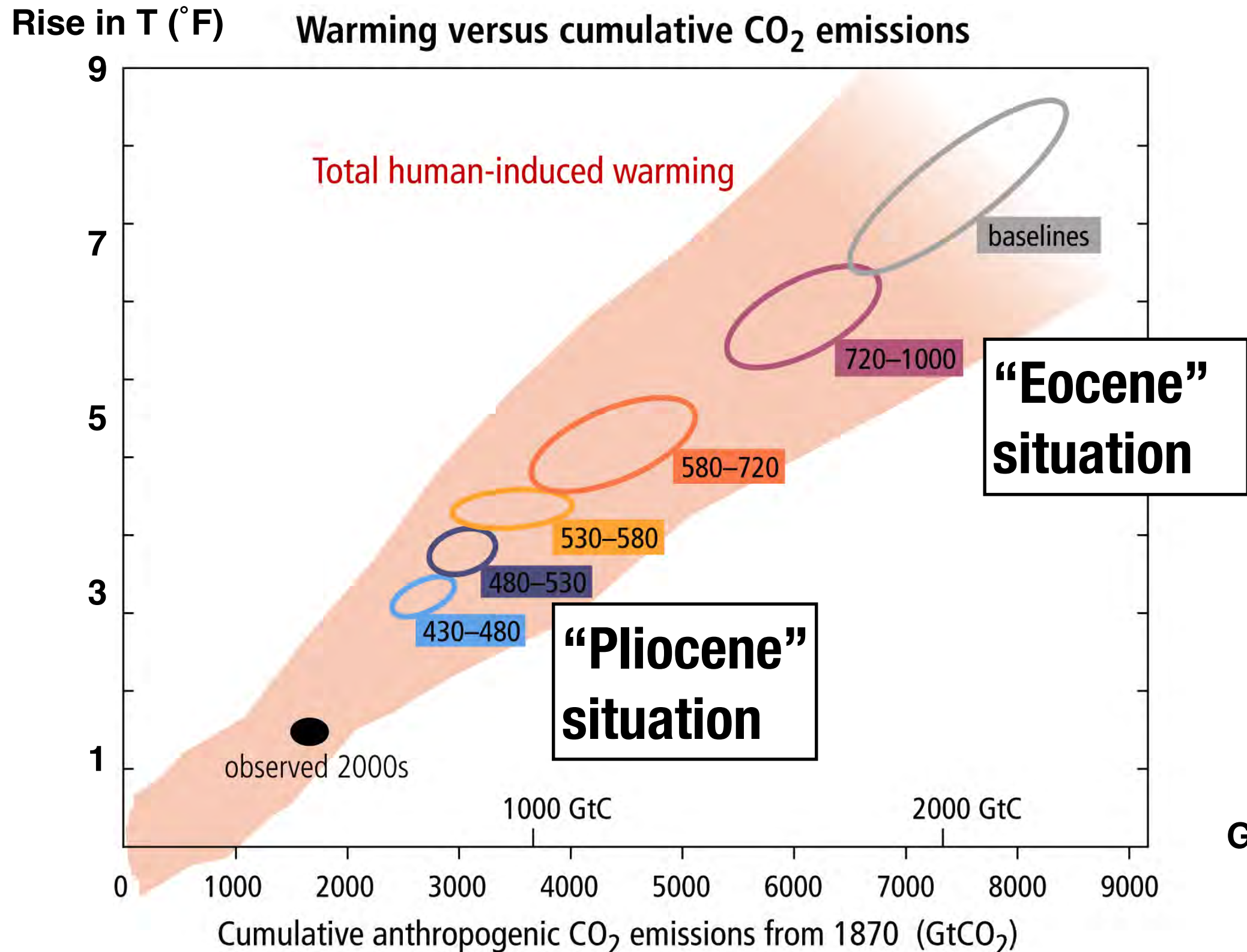
**It's Us.**

**It's Bad.**

**There's Hope.**



# Where we end up depends on how much we emit

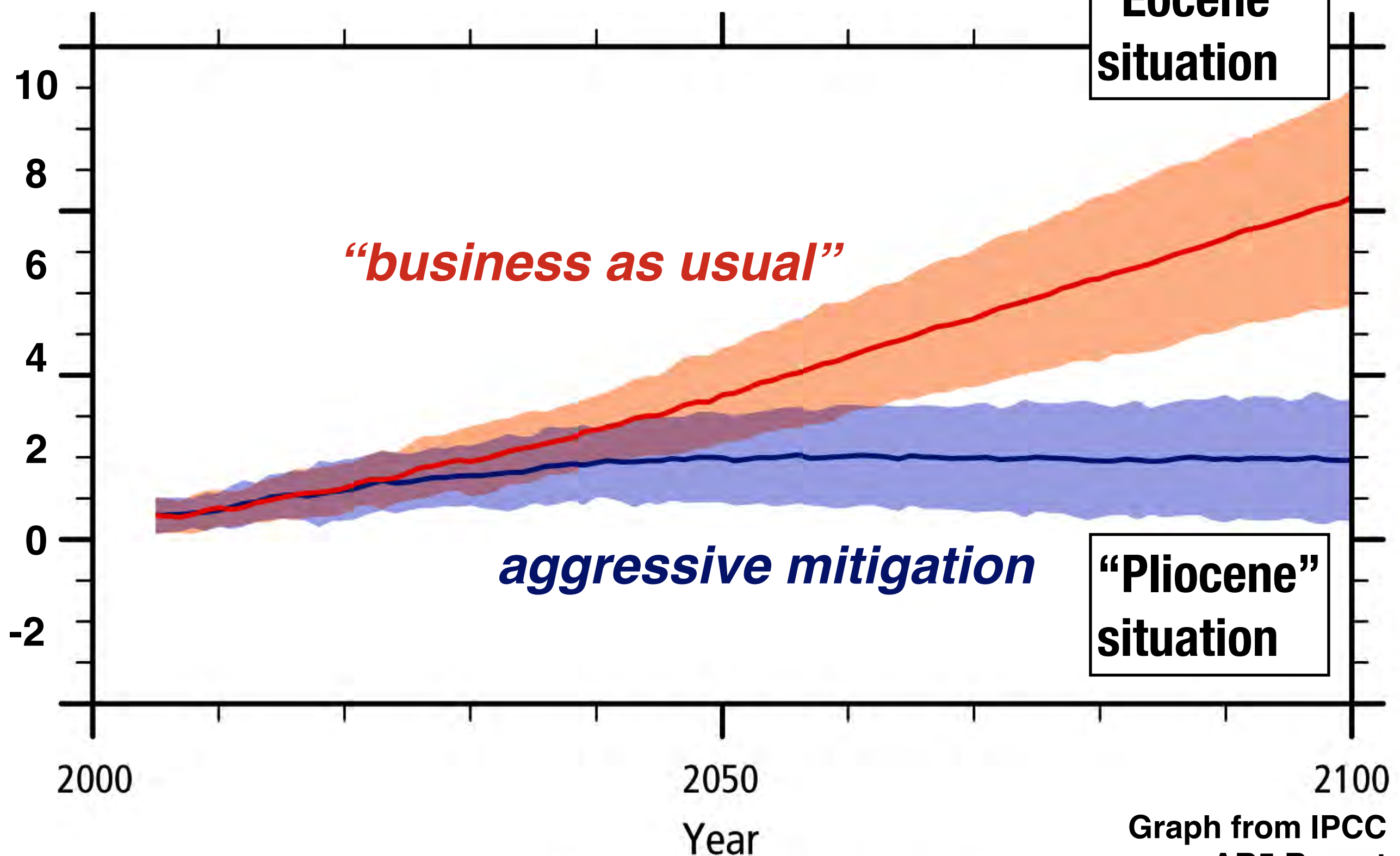


Graph from  
IPCC AR5  
Report



# Projected change in temperature

Rise in T (°F)



**“Eocene”  
situation**

***“business as usual”***

***aggressive mitigation***

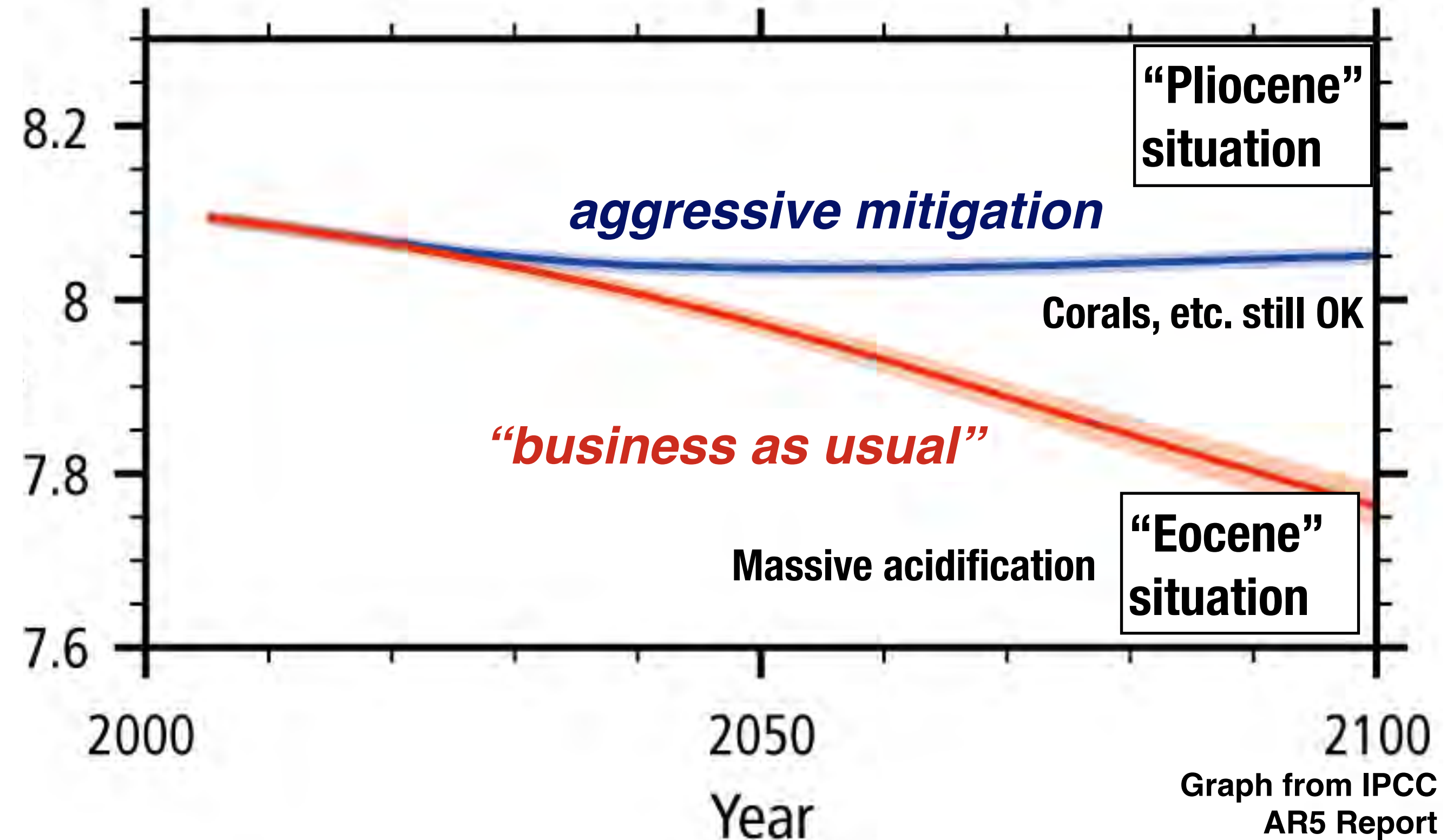
**“Pliocene”  
situation**

Graph from IPCC  
AR5 Report

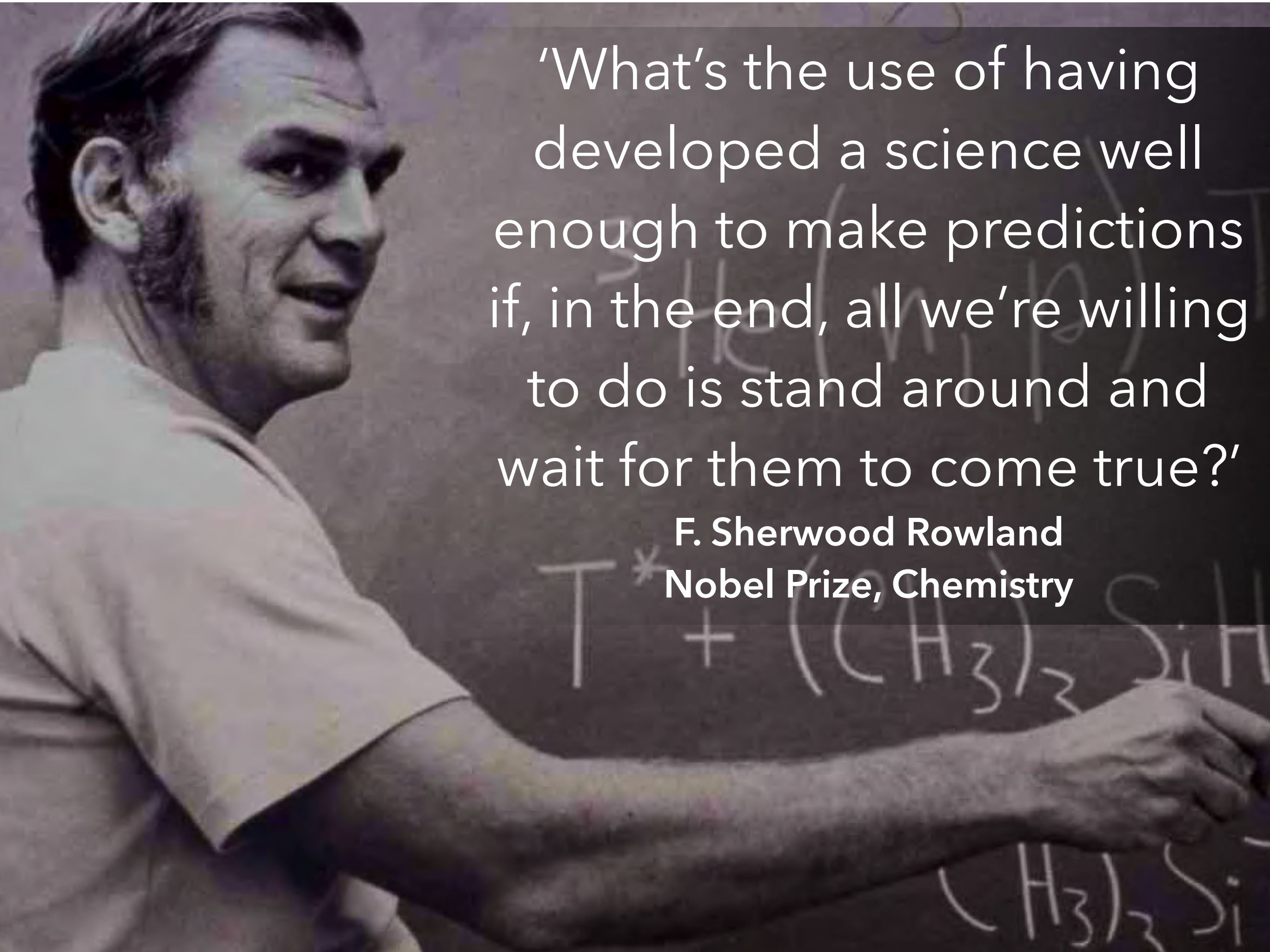


# Projected change in ocean acidity

Ocean pH





A black and white photograph of F. Sherwood Rowland, a man with a beard and mustache, wearing a light-colored short-sleeved shirt. He is standing in front of a chalkboard, looking towards the right. His right arm is extended, and he appears to be writing on the board. The chalkboard contains chemical equations, including  $T^* + (CH_3)_3SiH$  and  $(CH_3)_3Si$ .

'What's the use of having developed a science well enough to make predictions if, in the end, all we're willing to do is stand around and wait for them to come true?'

**F. Sherwood Rowland**  
**Nobel Prize, Chemistry**



# Thank You.



**@leafwax**

**<http://www.geo.arizona.edu/~jesst>**



**The worst global  
warming of all time...**





Photo by Jonathan Blair, National Geographic

**Dinogorgon**  
Late Permian predator



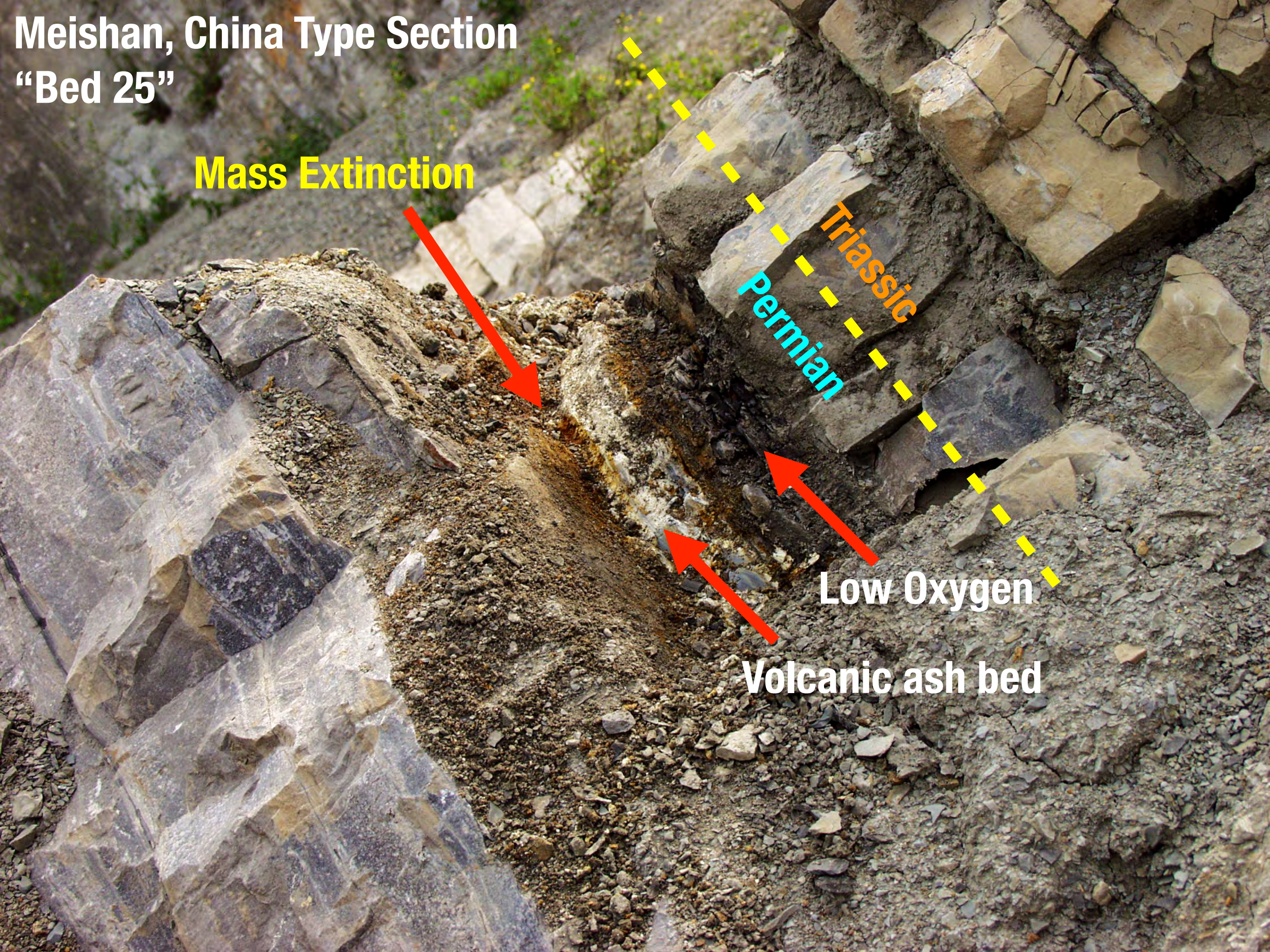
# The Late Permian: 250 million year ago











**Meishan, China Type Section**  
**“Bed 25”**

**Mass Extinction**

**Triassic**  
**Permian**

**Low Oxygen**

**Volcanic ash bed**