Earth’s climate trajectory
Past, present, future

Professor Jessica Tierney | University of Arizona
The journey towards a high CO$_2$ future has begun.
Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration

Data from Scripps CO₂ Program   Last updated April 2019

CO₂ Concentration (ppm)

Year

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 CO₂ in the atmosphere is has the chemical “fingerprint” of fossil fuels (very old, made from dead trees and algae).
Why should I care?
CO$_2$ heats things up and we have known that for a long time because of the greenhouse effect.

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)

Gamma Ray  X-Ray  Ultraviolet  Infrared  Microwave  Radio

shorter wavelength  longer wavelength
higher frequency  lower frequency
higher energy  lower energy
CO$_2$ vibrates with the infrared
Atmosphere

$T = 0^\circ F$

$T = 58^\circ F$

$T > 70^\circ F$
Global Temperatures
Land and Ocean

Temperature Anomaly (°F)

Year

1880 1900 1920 1940 1960 1980 2000

-1 -0.5 0 0.5 1 1.5 2
It’s Real

High tide in Miami Beach, FL
Extreme drought in California, 2015

It’s Real
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

- Tree Rings
- Ice Cores
- Stalagmites
- Sediments
- Corals
Current GHG concentrations have no analog in the last 800,000 years.
Core Sampling
Stuff you can measure in mud

**Microfossils**

- Coccoliths
- Foraminifera
- Dinoflagellates
- Pollen

**Chemical properties**

- Molecular fossils

**Physical properties**

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

**Stuff you can measure in mud**

- Microfossils
  - Coccoliths
  - Foraminifera
  - Dinoflagellates
  - Pollen

- Chemical properties
  - Molecular fossils

- Physical properties
  - $^{230}\text{Th}_{xs}$ isotopes

- Diagram showing microscopic images of various microfossils and chemical structures.
Foraminifera
Chemical measurements in foraminifera tell us...

The last time CO$_2$ was this high was 2.5 million years ago.

From the collection of Gavin Foster et al., 2017
Welcome to the Pliocene

- 3°F warmer in the mid-latitudes
- 7°F warmer in the higher latitudes

Climate model simulation by Ran Feng
(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

- Last time CO₂ was 400 ppm
- Antarctic ice sheet forms
- Today’s temperature

Global Temperature (°F)
Temperature followed CO₂

Global Temperature (°F)

“Greenhouse” climates

CO₂ (ppm)

Age (Ma)
What are “greenhouse climates” like?

Giant boid snake from the Palaeocene neotropics reveals hotter past equatorial temperatures


The largest extant snakes live in the tropics of South America and southeast Asia1–3 where high temperatures facilitate the evolution of large body sizes among air-breathing animals whose body temperatures are dependant on ambient environmental temperatures (poikilothermy)4,5. Very little is known about ancient tropical terrestrial ecosystems, limiting our understanding of the evolution of giant snakes and their relationship to climate in the past. Here we describe a boid snake from the oldest known neotropical rainforest fauna from the Cerrejón Formation (58–60 Myr ago) in northeastern Colombia. We estimate a body length of 13 m and a mass of 1,135 kg, making it the largest known snake6–9. The maximum size of poikilothermic animals at a given temperature is limited by metabolic rate4, and a snake of this size would require a minimum mean annual temperature of 30–34°C to survive. This estimate is consistent with hypotheses of hot Palaeocene neotropics with high concentrations of atmospheric CO2 based on climate models 10.

Comparison of palaeotemperature estimates from the equator to those from South American mid-latitudes indicates a relatively steep temperature gradient during the early Palaeogene greenhouse, similar to that of today. Depositional environments and faunal composition of the Cerrejón Formation indicate an anaconda-like ecology for the giant snake, and an earliest Cenozoic origin of neotropical vertebrate faunas.

Serpentes Linnaeus 1758
Boidae Gray 1825
Boinae Gray 1825
Titanoboa cerrejonensis gen. et sp. nov.

Etymology. The generic name combines 'Titan' (Greek, giant) with 'Boa', type genus for Boinae. The specific name refers to the Cerrejón region, Guajira Department, Colombia. The full translation is 'titanic boa from Cerrejón'.

Holotype. UF/IGM 1, a single precloacal vertebra (Fig. 1a–d).

Locality. La Puente Pit, Cerrejón Coal Mine, Guajira Peninsula, Colombia (palaeolatitude 5.5°N; Supplementary Fig. 1).

Horizon. Single claystone layer, middle segment of the Cerrejón Formation (Supplementary Fig. 2); middle–late Palaeocene epoch (58–60 Myr ago), palynological zone Cu-02 (ref. 11).

Referred material. UF/IGM 2 (paratype), nearly complete precloacal vertebra (Fig. 1g, h). UF/IGM 3–UF/IGM 28, 184 additional precloacal vertebrae and ribs representing 28 individuals (Supplementary Table 1).
Welcome to the Eocene

56-34 million years ago. CO₂ near 1000 ppm. No polar ice. The climate was steamy...
Crocs lived in the Arctic!

Preferred temperature range for crocs

After Markwick, 1998

70°F 85°F 100°F
Palms and baobab grew in Antarctica

Pross et al., 2012
A more “equable” climate...

Today’s ocean temperatures

Eocene ocean temperatures
But not a stable climate…

"The Paleocene-Eocene Thermal Maximum"
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...

Before PETM:
sediments rich in carbonate

Sharp boundary = PETM.
Ocean acidifies, seafloor carbonate dissolves

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

100,000s yrs later:
Calcareous sediments return = ocean recovers
Where did the CO₂ 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 CO₂. Except, the CO₂ rise happening now is way faster than the PETM.

**Modern:** Fueled by high emission rates (up to 25 petagrams of carbon a year), global temperature is rising quickly and will level off only when emissions cease.

**PETM:** Slow but steady emissions (up to 1.7 petagrams of carbon a year) resulted in a more gradual heating of the planet some 56 million years ago.

Greenhouse gas release begins | Duration (years) | 20,000
---|---|---
0 | 10,000 | 20,000

Graph by Lee Kump, 2011, Scientific American
It’s Real.
It’s Us.
It’s Bad.
There’s Hope.
Where we end up depends on how much we emit.

- **“Eocene” situation**
- **“Pliocene” situation**

Rise in $T$ ($^\circ$F) vs. Warming versus cumulative $\text{CO}_2$ emissions from 1870 (GtCO$_2$).

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

- **“Pliocene” situation**
- **“Eocene” situation**
- **aggressive mitigation**
- **“business as usual”**
- Massively acidification
- Corals, etc. still OK

Graph from IPCC AR5 Report
'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...
Dinogorgon
Late Permian predator
The Late Permian: 250 million year ago
Meishan, China Type Section
“Bed 25”

Mass Extinction

Volcanic ash bed

Low Oxygen

Triassic

Permian

Volcanic ash bed