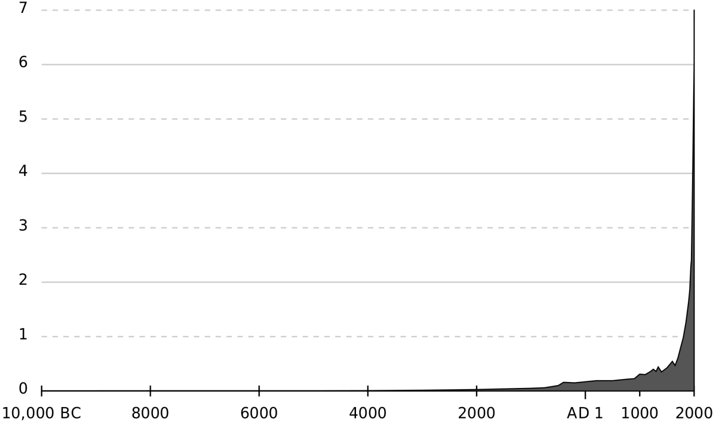
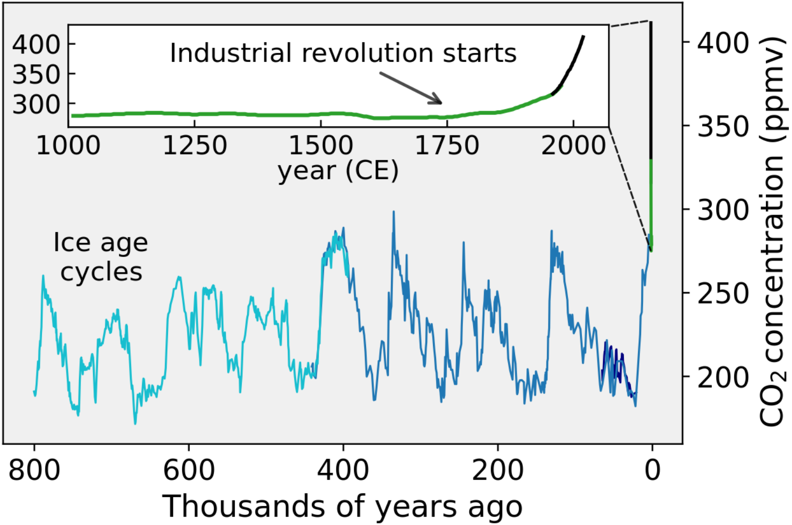
LIFE'S STRUGGLE TO SURVIVE

John Baez

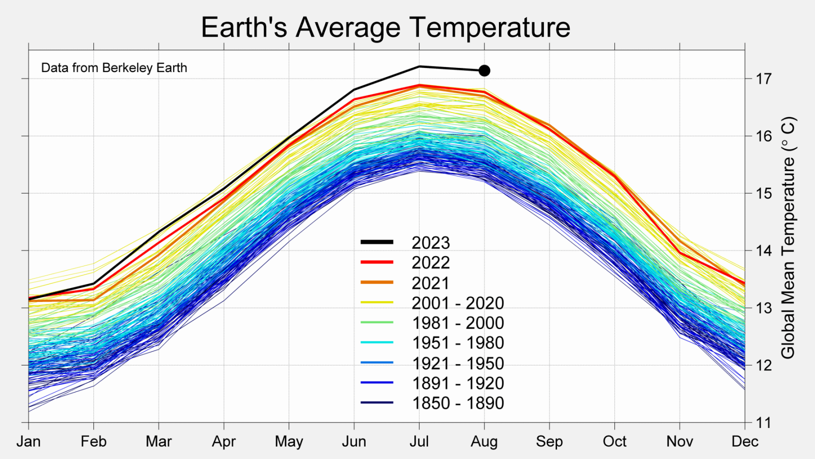
We have left the Holocene and entered a new epoch: the Anthropocene, when the biosphere is rapidly changing due to human activities.



THE EARTH'S POPULATION, IN BILLIONS



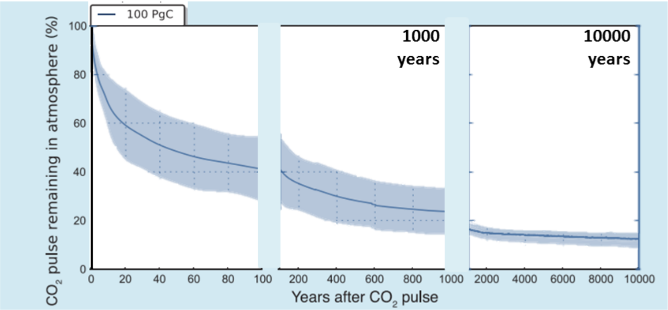
Industrial revolution starts
400
350
300
1000
1250
1500
1750
2000
year (CE)
Ice age
cycles
400
350
300
250
200
CO_2 concentration (ppmv)
800
600
400
200
0
Thousands of years ago



Earth's Average Temperature
Data from Berkeley Earth
2023
2022
2021
2001 - 2020
1981 - 2000
1951 - 1980
1921 - 1950
1891 - 1920
1850 - 1890
Global Mean Temperature (° C)
11
12
13
14
15
16
17
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

We are changing not just the present but the far future.

Once CO_2 enters the atmosphere, it stays there for hundred of years.



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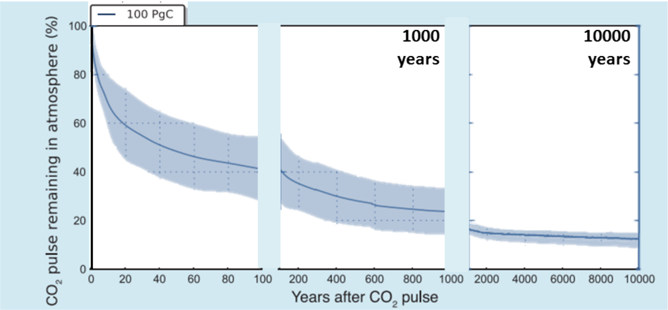

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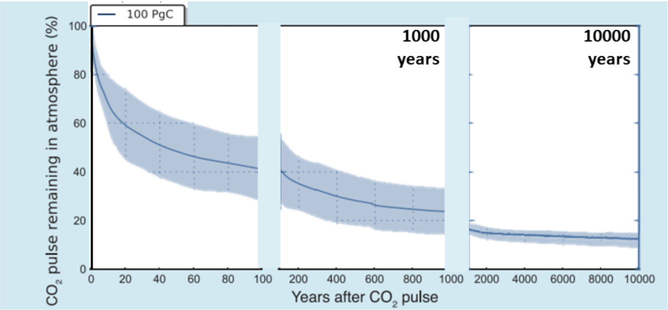

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But the Anthropocene is much more than just global warming.

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- 8-9 times as much phosphorus is flowing into oceans than the natural background rate.

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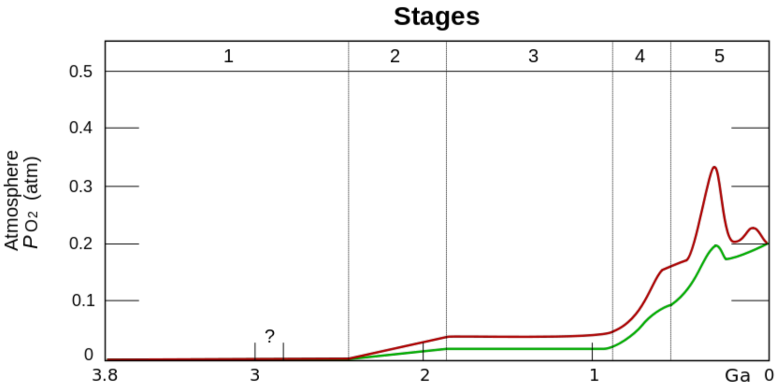
Sometime between 2.7 and 2.3 billion years ago, photosynthesizing organisms started dumping lots of a deadly gas into the atmosphere: *oxygen!*

Banded iron formation, 2.1 billion years old.

Oxygen, poisonous to all life at the time, was first absorbed by dissolved iron and organic matter—but eventually there was too much. Concentrations shot up... and most life on Earth may have died! This was the Oxygen Catastrophe:



As oxygen entered the atmosphere, *methane* — a powerful greenhouse gas — was eliminated. This may have caused the most severe ice age in history: the Huronian glaciation, from 2.4 to 2.1 billion years ago.

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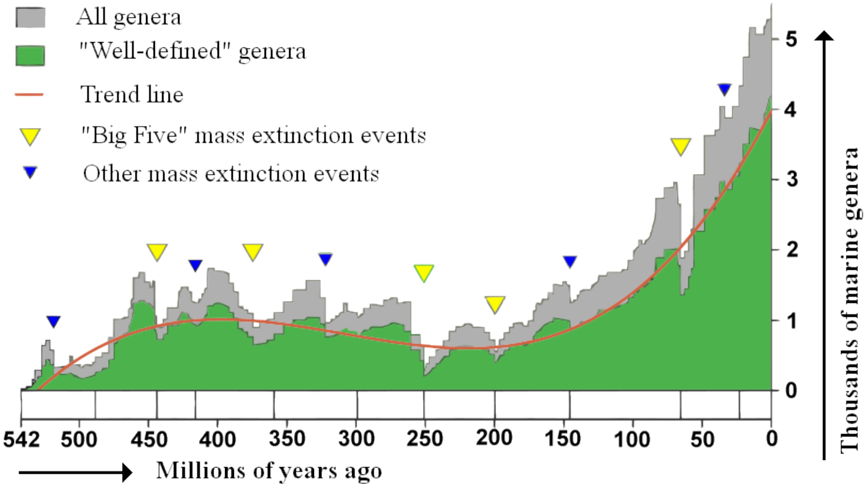
Luckily all this happened slowly enough that evolution saved the day! Organisms developed that could survive and even *use* oxgen.

Around 540 million years ago, the first *multicellular life* arose.

Since then, there have been 5 really big mass extinctions:



Rohde and Muller, "Cycles in fossil diversity"

Here are the 'Big Five':

1. The Ordovician-Silurian Extinction, 445 million years ago. 85% of marine species went extinct.

This was the second biggest of the 'big five'.

In the Ordovician, most life was in the seas.

What caused the Ordovician-Silurian extinction? There was a phase of global cooling, and so much glaciation that sea levels were drastically lowered. Later, as the glaciers melted, there was a second pulse of extinctions, perhaps due to lowered oxygen levels in the water.

It took 5 million years for biodiversity to recover.

2. The Late Devonian Extinction, 372–359 million years ago. 70% of marine species went extinct.

By the Devonian there was life on land, but this extinction seems to have only affected marine life. Many scientists suspect another bout of global cooling. There were also shortages of oxygen in ocean bottom waters.

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This extinction was not sudden. There were several waves of extinction, over a period lasting 25 million years. Coral reefs fully recovered only 120 million years later!

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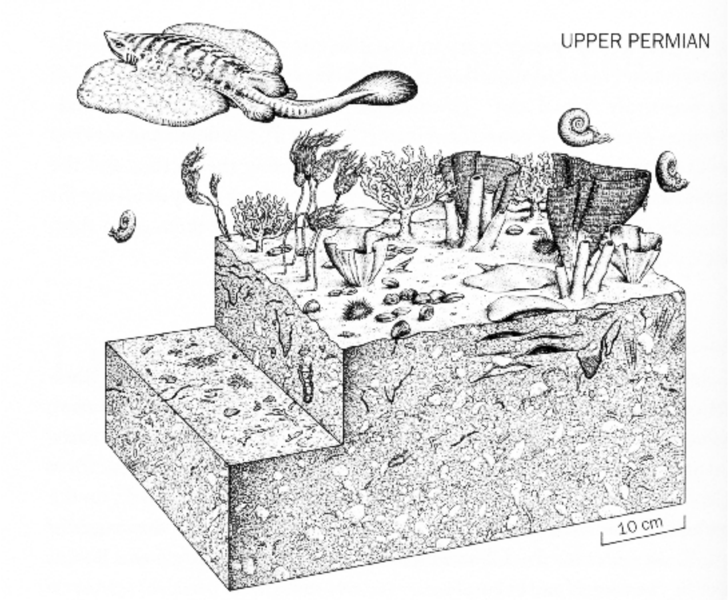
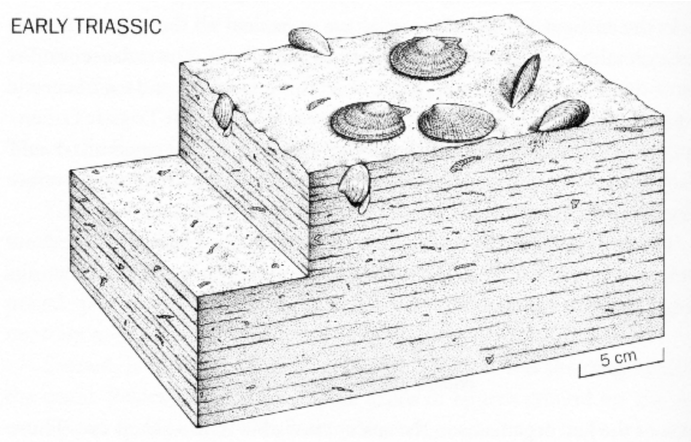
Before this extinction, seabeds near China looked something like this...



From Michael Benton, *When Life Nearly Died: The Greatest Mass Extinction of All Time*

Afterwards, they looked like this:



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The amount of carbon dioxide in the air shot up from around 400 ppm to 2,500 ppm. Maybe this was caused a massive release of methane from clathrates under the ocean.

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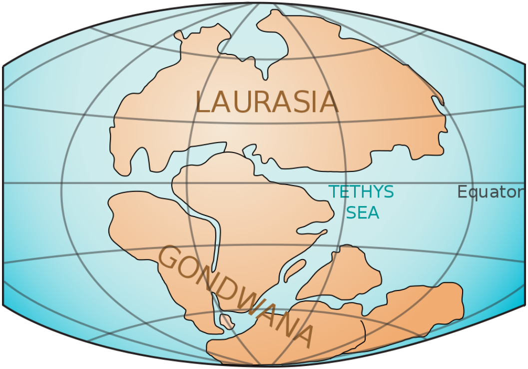
By the end of the Triassic there was again a variety of reptiles on land and in sea. The extinction at the end of the Triassic destroyed many of these reptiles, and the last of the large amphibians...

... opening niches for the dinosaurs of the Jurassic.

Nobody is sure what caused the Triassic-Jurassic extinction. But about this time, the supercontinent Pangaea began splitting into Laurasia and Gondwana, with massive floods of lava in the Central Atlantic Magmatic Province — perhaps one of the largest igneous events in the Earth's history.



TRIASSIC
200 million years ago

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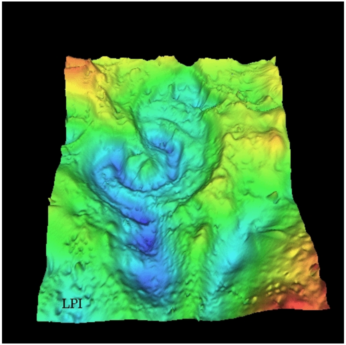
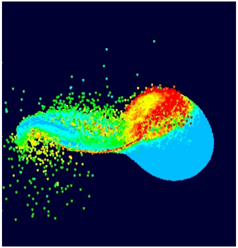
This is the famous one that killed off the dinosaurs. It's probably due to the asteroid that hit Chicxulub. This was 10 kilometers across and delivered an energy of 100 teratons of TNT: 2 million times the largest manmade bomb, the 57-megaton Tsar Bomba.



The asteroid that killed off the dinosaurs was nothing compared to planet that hit the Earth and formed the moon 4.53 billion years ago... according to the Giant Impact Hypothesis:



To make our Moon, Robin Canup simulated a collision with 'planet Theia', slightly bigger than Mars, moving slowly towards the Earth. 50 minutes after it hit it it looked like this: half the Earth's surface is red-hot.

After 5 hours, the iron core of Theia and most of the the debris comes crashing back down. The Earth's entire crust and outer mantle melts. A quarter of Theia has actually vaporized!

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After a day, a ring of debris orbits the Earth. Within a century, it collects to form the Moon we know and love. Meanwhile, Theia's iron core sinks down to the center of the Earth!

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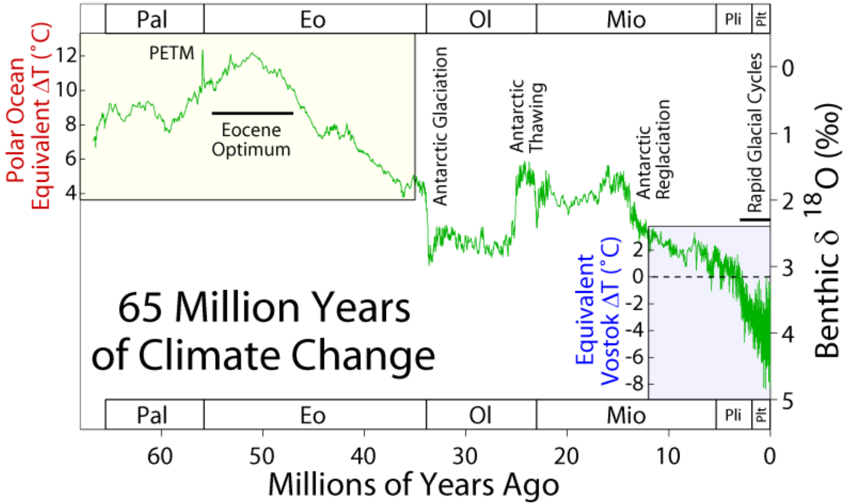
1. How stable is the Earth's climate? The 'clathrate gun hypothesis' says that methane locked in sea beds can escape, driving rapid global warming. These reserves contain 1500-2000 billion tonnes of carbon — large compared to the 5000 contained in the rest of the biosphere! Methane is ~ 25 times as potent a greenhouse gas as carbon dioxide, for its first century in the air.

The clathrate gun hypothesis could help explain the Paleocene -Eocene Thermal Maximum (PETM), when temperatures shot up 6° C in just 20,000 years and stayed hot for ∼200,000 years:



In the past century, temperatures have been rising ~ 40 times faster than in the PETM. Luckily, we're starting from a much colder temperature. Methane is already bubbling up from Arctic oceans at ~ 12 million tonnes of carbon/year. This is tiny compared to the ~ 10 billion tonnes/year from our carbon burning activities, but unsettling:

Methane bubbling up from the East Siberian Arctic Shelf — Natalia Shakhova

2. How will our civilization respond to the Anthropocene?

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Will we change our ways fast enough to survive and even prosper?

Will our civilization collapse but humanity survive?

Or will we make way for other species?