Geologic Evolution of Earth's Atmosphere

AOSC 680

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2024
https://umd.instructure.com/courses/1367293

https://www.videoblocks.com/video/earth-sunset-spacewalk-view-from-space-station-r7dydlcsgjd23vml0

Lecture 1

29 August 2024

Announcements

1) AOSC Weekly Seminars Thurs, 3:30 pm, ATL 2400 https://aosc.umd.edu/seminars

2) Re-load button needed for viewing peer-reviewed literature from off campus:
https://lib.guides.umd.edu/reload-button

2. Schedule

Date	Lecture Topic	Required Reading	Admis. Tickets	Lecture Notes	Problem Sets	Additional Readings	Learning Outcome
08/27	Class Overview	No reading for first meeting	No AT	Lecture 0 Video			No Quiz
08/29	Geological Evolution of Earth's Atmosphere	Paris Beacon of Hope Sec 1.1, 1.2 (intro), and 1.2.1 (11.5 pages)	AT 1	Lecture 1 Video		Meckler *et al.*, *Science*, 2022 Excellent news article on Meckler *et al.* study Ivany and Salawitch, *Geology*, 1993 NOVA: The Day The Dinosaurs Died BBC Article, Life on Mars Webster et al., *Science*, 2014	Quiz 1
09/03	Overview of Global Warming	Climate Change Evidence and Causes, Royal Society (36 pages) IPCC 2007 FAQ (1.1, 1.2, 1.3, 2.1, & 3.1) (11 pages) Paris Beacon of Hope Sec 1.2.2 (3 pages)	AT 2	Lecture 2 Video		Kerr, *Science*, 2007 Warming Animation ENSO Video Entire IPCC 2007 FAQ News story 1, Antarctic Ice News Story 2, Antarctic Glacier	Quiz 2

Link to video of first lecture

https://www2.atmos.umd.edu/~rjs/class/fall2024/lectures/AOSC680_2024_lecture01_handout.pdf

https://www2.atmos.umd.edu/~rjs/class/fall2024

Announcements

Lecture will be given in class

Will meet Tues before Thanksgiving

Meeting Number	Date	Topic
1	8/27	Class Overview
2	8/29	Geological Evolution of Earth's Atmosphere
3	9/03	Overview of Global Warming
4	09/05	***Fundamentals of Earth's Atmosphere***
5	9/10	Climates of the Past
6	9/12	Global Carbon Cycle
7	9/17	Methane and Nitrous Oxide
8	9/19	Radiative Forcing
9	9/24	Climate Basics & Atmospheric Energy Flow (DR)
10	9/26	Water Vapor, Aerosol, Cloud, & Albedo Feedbacks
11	10/01	Review for Exam
12	10/03	Exam
13	10/08	Writing a Good Paper, Giving a Good Talk, Path Forward
14	10/10	Student 1

Meeting Number	Date	Topic
15	10/15	Student 2
16	10/17	Student 3
17	10/22	Student 4
18	10/24	Student 5
19	10/29	Student 6
20	10/31	Student 7
21	11/05	Student 8
22	11/07	Student 9
23	11/12	Student 10
24	11/14	Student 11
25	11/19	Student 12
26	11/21	Student 13
27	**11/26**	***Student 14***
28	12/03	Presentation Day 1
29	12/05	Presentation Day 2

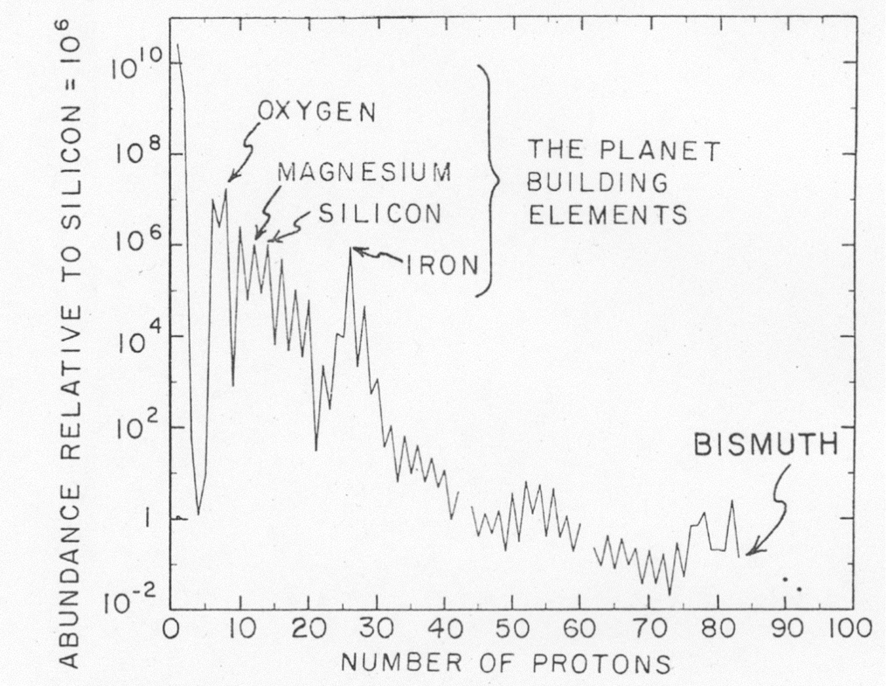
Schedule has been updated at: https://www2.atmos.umd.edu/~rjs/class/fall2024

Geological Evolution of Earth's Atmosphere: *"In the Beginning"*

- **Assemblage of 92 natural elements**

- **Elemental composition of Earth basically unchanged over 4.5 Gyr**
  - Gravitational escape restricted to a few gases (H, He)
  - Extra-terrestrial inputs (comets, meteorites) relatively unimportant

- **Biogeochemical cycling of elements between reservoirs of Earth "system" determines atmospheric composition**

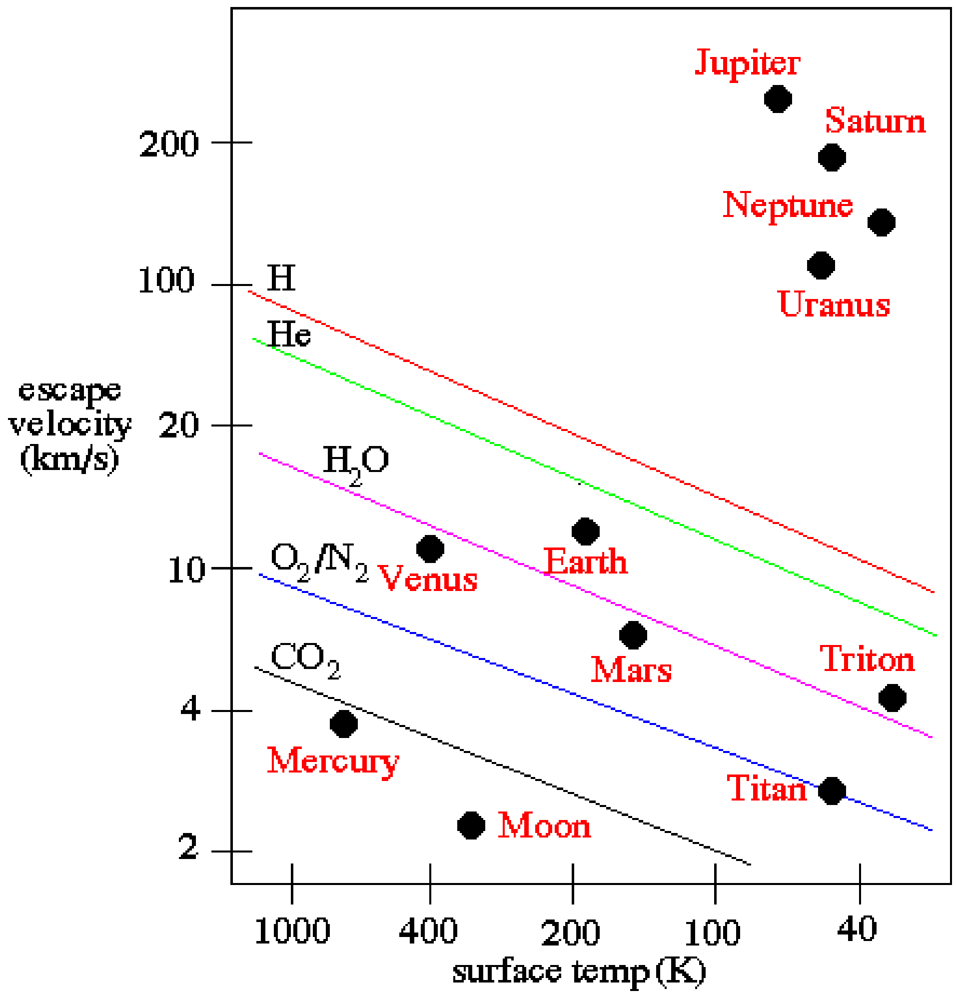


From "How to Build a Habitable Planet"
By W.S. Broecker, ELDIGIO Press, pg 57

Geological Evolution of Earth's Atmosphere: *Earth, Mars, and Venus*

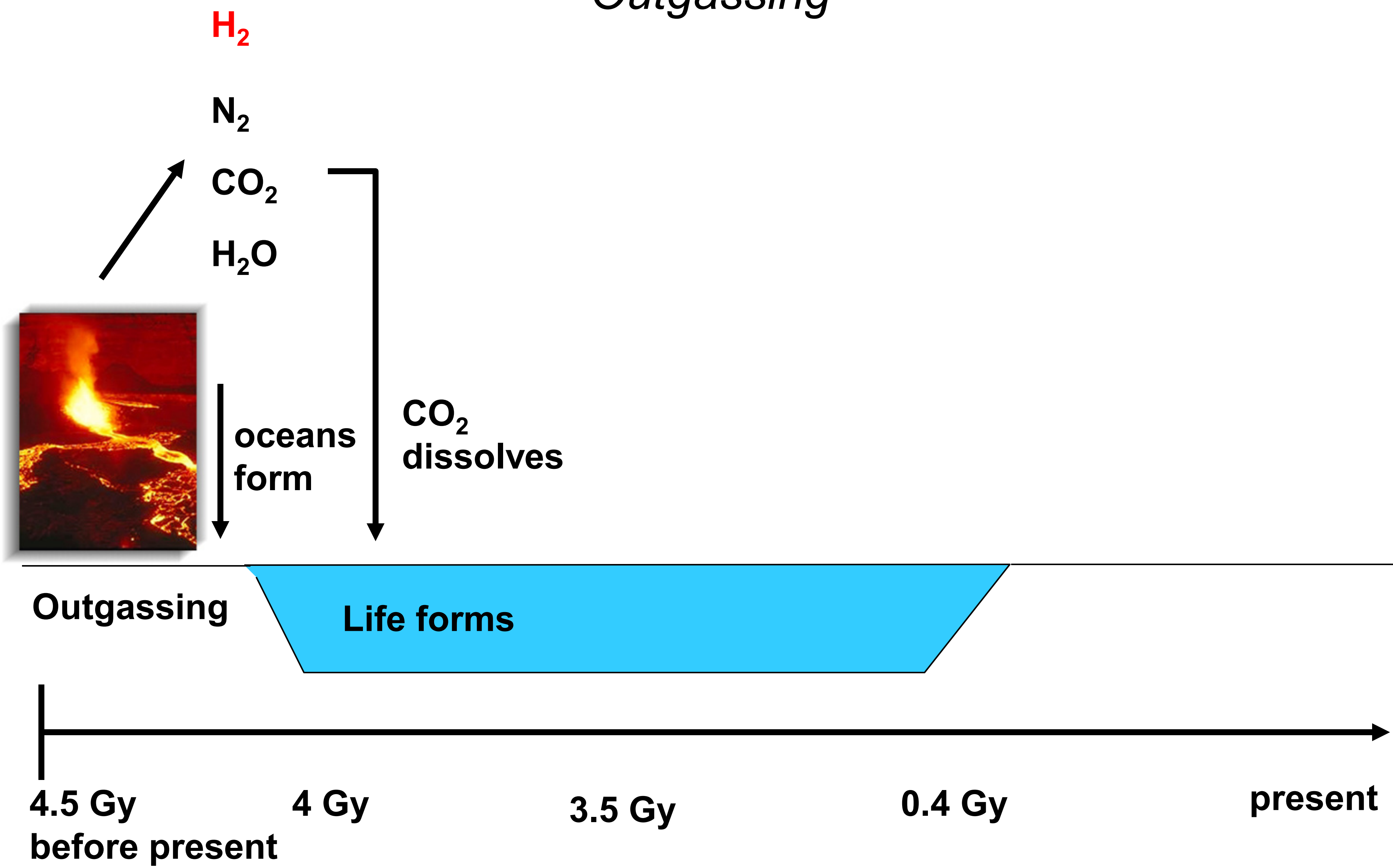
	Earth	Venus	Mars
Radius (km)	6400	6100	3400
Mass (10^{24} kg)	6.0	4.9	0.6
Albedo	0.3	0.8	0.22
Distance from Sun (A.U.)	1	0.72	1.52
Surface Pressure (atm)	1	91	0.007
Surface Temperature (K)	~15 °C	~ 460 °C	–140 °C to 20 °C
N_2 (mol/mol)	0.78	3.4×10^{-2}	2.7×10^{-2}
O_2 (mol/mol)	0.21	6.9×10^{-5}	1.3×10^{-3}
CO_2 (mol/mol)	3.7×10^{-4}	0.96	0.95
H_2O (mol/mol)	1×10^{-2}	3×10^{-3}	3×10^{-4}
SO_2 (mol/mol)	1×10^{-9}	1.5×10^{-4}	Nil
Cloud Composition	H_2O	H_2SO_4	Mineral Dust

Geological Evolution of Earth's Atmosphere:
Earth, Mars, and Venus



http://abyss.uoregon.edu/~js/ast121/lectures/lec14.html

Geological Evolution of Earth’s Atmosphere: *Outgassing*



Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Reducing Environment

Decreasing oxidation number (reduction reactions)

-3	0	+1	+2	+3	+4	+5
NH_3 Ammonia	N_2	N_2O Nitrous oxide	NO Nitric oxide	HONO Nitrous acid NO_2^- Nitrite	NO_2 Nitrogen dioxide	HNO_3 Nitric acid NO_3^- Nitrate

Increasing oxidation number (oxidation reactions)

Oxidation state represents number of electrons:
added to an element (– oxidation state) or
removed from an element (+ oxidation state)

Oxidation state of a compound: $\sum = -2 \times$ # O atoms + $1 \times$ # H atoms;
Oxidation of element = Electrical Charge – $\sum$

Note: there are some exceptions to this rule, such as oxygen in peroxides

Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Reducing Environment

Decreasing oxidation number (reduction reactions)

-4	0	+2	+4
CH_4 **Methane**	CH_2O **Formaldehyde**	CO **Carbon Monoxide**	CO_2 **Carbon dioxide**

Increasing oxidation number (oxidation reactions)

Oxidation state represents number of electrons:
added to an element (– oxidation state) or
removed from an element (+ oxidation state)

Oxidation state of a compound: $\sum = -2 \times \#\text{ O atoms} + 1 \times \#\text{ H atoms}$;
Oxidation of element = Electrical Charge $- \sum$

Note: there are some exceptions to this rule, such as oxygen in peroxides

Methane On Mars: *Sign of Life ?*

The Earth's deepest living organisms may hold clues to alien life on Mars

Michael Marshall *Martian life, if it exists, could well be subterranean*

To understand the life that might survive deep below Mars' surface, we can look to some of the deepest, and oldest, forms of living organism on our own planet.

Mars isn't just the red planet: it's also a wet planet. On 12 August, US researchers reported evidence of a vast reservoir of liquid water, deep in the rocky crust of the planet.

The data came from Nasa's Mars Insight Lander, which recorded more than 1,300 Marsquakes over four years. Researchers led by Vashan Wright, a geophysicist at the University of California San Diego's Scripps Institution of Oceanography, studied the seismic waves that reached the lander and concluded that they had passed through layers of wet rock. While the surface of Mars is a barren desert, Wright's data suggests considerable volumes of water are locked up in rocks between 11.5 and 20km (7.1-12.4 miles) down.

Because it is pitch-black, these microbes cannot get energy directly from sunlight, as photosynthetic organisms at the surface do. "The really important thing to note is that they don't depend, by and large, on the Sun," says Karen Lloyd, a subsurface microbiologist at the University of Southern California in Los Angeles.

They also aren't receiving any other inputs such as nutrients from above. Many of these deep ecosystems are "completely disconnected from the surface", says Cara Magnabosco, a geobiologist at ETH Zurich in Switzerland.

Instead, these ecosystems are based on chemosynthesis. The microbes get their energy by performing chemical reactions, taking in chemicals from the surrounding rocks and water. For instance, they may use gases such as methane or hydrogen sulphide as their source material. "The subsurface has many, many different chemical reactions," says Lloyd. "A lot of us spend a lot of time finding new reactions that support life."

https://www.bbc.com/future/article/20240821-could-alien-life-survive-in-deep-lakes-below-mars-surface

Methane On Mars: *Sign of Life ?*

The Earth's deepest living organisms may hold clues to alien life on Mars

Michael Marshall *Martian life, if it exists, could well be subterranean*

The most suggestive evidence of life to date is the **plumes of methane in the Martian air**, which **vary with the seasons**. On Earth, methane is often made by microorganisms – so the gas could be a waste product from underground life. However, Lloyd urges caution. "There are many non-life reasons why there could be plumes of methane," says Magnabosco.

Martian microbes

So far there is no solid or direct evidence of life on Mars, despite decades of uncrewed missions to the red planet. The surface is dry and cold, and no living organism has ever wandered into shot of a Mars rover camera.

However, features like canyons strongly suggest that Mars did have running water on its surface billions of years ago. Some of that water was probably lost to space, but Wright's team concluded that much of it is underground.

"We know that water is a prerequisite for life as we know it," says Lloyd. So perhaps the Martian surface used to be habitable, and now only the subsurface is. "I've always preferred the notion that life would be buried somehow," she says.

Like the slow microbes living deep under Earth's oceans, **Martian microbes may be clinging to life** despite scant nutrients. "The same sort of processes that happen in our subsurface can happen on Mars," says Magnabosco.

> *If life was able to develop on Mars, it has a very good chance of still surviving and being on Mars today – Cara Magnabosco*

https://www.bbc.com/future/article/20240821-could-alien-life-survive-in-deep-lakes-below-mars-surface

Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Reducing Environment

How do we know early atmosphere was reducing ?

Why was a reducing environment important ?

Geological Evolution of Earth's Atmosphere: *Onset of Photosynthesis*

H_2

N_2

CO_2

H_2O

Incipient rise of O_2 in the ancient atmosphere signaled by first appearance of continental red-beds of ferric iron (about 2 Gy B.P.)

oceans form

CO_2 dissolves

O_2

Outgassing

Life forms

Onset of photosynthesis

4.5 Gy before present

4 Gy

3.5 Gy

0.4 Gy

present

Geological Evolution of Earth's Atmosphere: *Atmospheric O_2 on Geological Time Scales*

- **Rise of atmospheric O_2 linked to evolution of life:**

The rise of atmospheric O_2 that occurred ~2.4 billion years ago was the greatest *environmental* crisis the Earth has endured. [O_2] rose from one part in a million to one part in five: from 0.00001 to 21% ! Earth's original biosphere was like an alien planet. Photosynthetic bacteria, frantic for hydrogen, discovered water and its use led to the build up of atomic O, a toxic waste product.

Many kinds of microbes were wiped out. O and light together were lethal. The resulting O-rich environment tested the ingenuity of microbes, especially those non-mobile microorganisms unable to escape the newly abundant reactive atmospheric gas. The microbes that survived invented various intracellular mechanisms to protect themselves from and eventually exploit this most dangerous pollutant.

Lynn Margulis and Dorion Sagan, Microcosmos: Four Billion Years of Microbial Evolution, 1986

Photosynthesis

Purple Sulfur Bacteria: Black Sea, lakes such as Palau, and early Earth

$$6CO_2 + 12\ H_2S + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6\ H_2O + 12S$$

$C_6H_{12}O_6$: Glucose

Modern Plants:

$$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Rather than looking for fossils, microbiologists studying low-oxygen environments extract organic residues from the strata [layer of rock or sediment] at sampling sites, known as ***biomarkers*** of chemical fossils. Microbiologists studying modern organisms discern which ***biomarker*** (that is, distinctive lipids [waxy, oily compounds insoluble in water yet soluble in certain organic solutions]) present in cell membranes) comes from modern organisms. ***Biomarker*** research on rocks that pre-date plants and animals are used to determine when life emerged on Earth [about 3.8 billion years ago, or 3.8 Bybp or 3.8 Gy before present] as well as how cellular life evolved, prior to the emergence of plants and animals.

Under A Green Sky, Peter D. Ward

Geological Evolution of Earth's Atmosphere: *Atmospheric O_2 on Geological Time Scales*

- **Rise of atmospheric O_2 linked to evolution of life:**

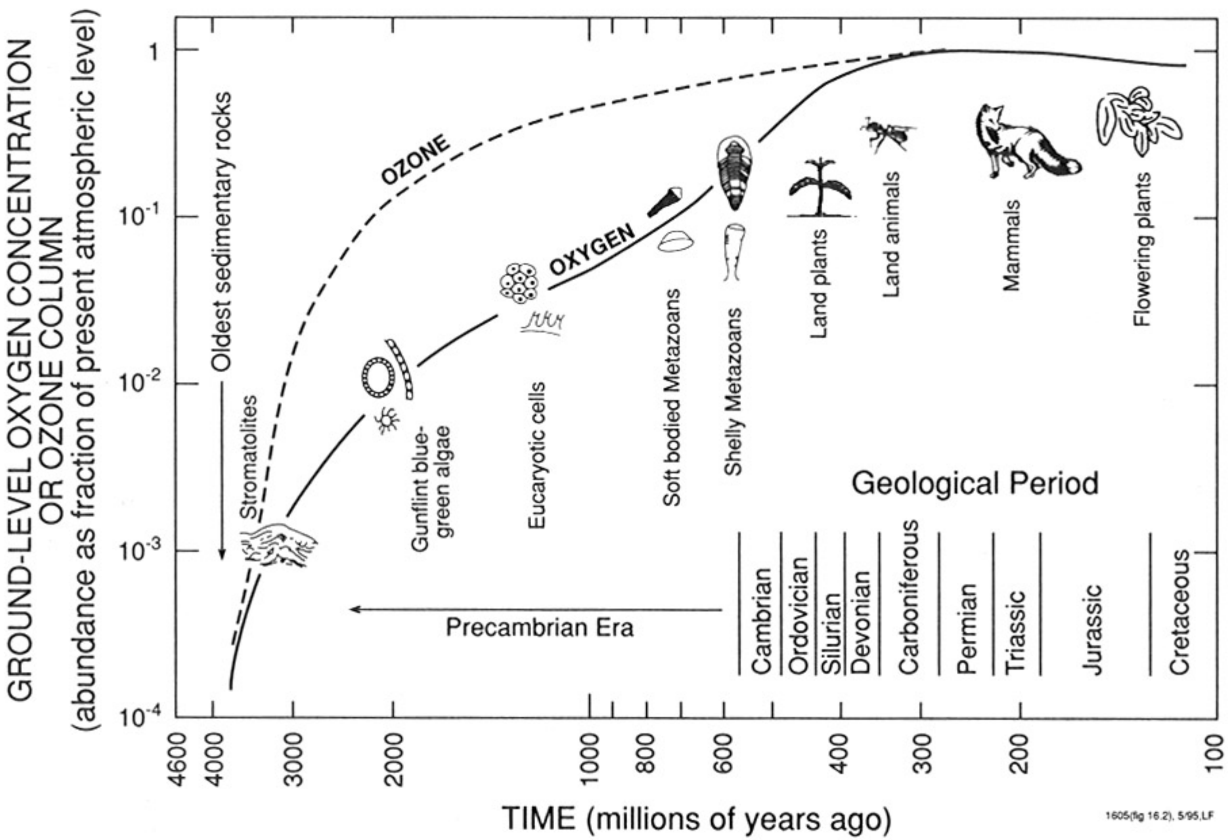


Figure 16.3. *Probable evolution of the oxygen and ozone abundance in the atmosphere (fraction of present levels) during the different geological periods of the Earth's history (Wayne, 1991; reprinted by permission of Oxford University Press).*

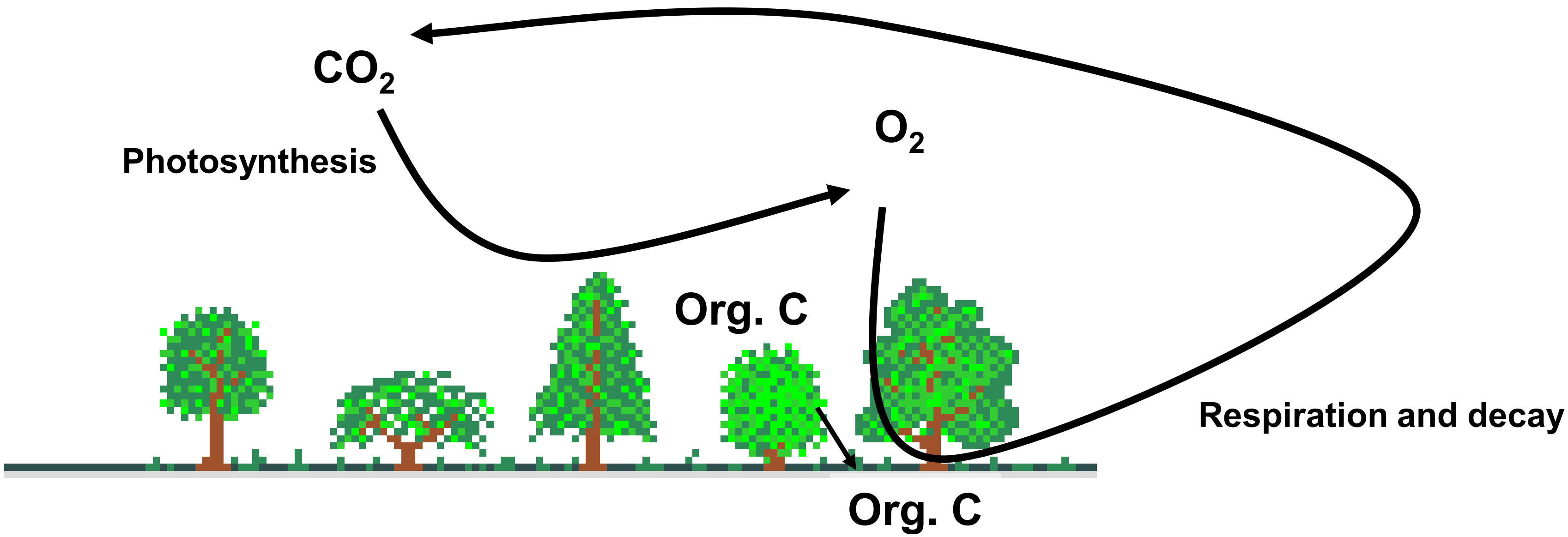
Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Photosynthesis

- **Photosynthesis: Source of O_2**

$$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

- **Respiration and Decay: Sink of O_2**

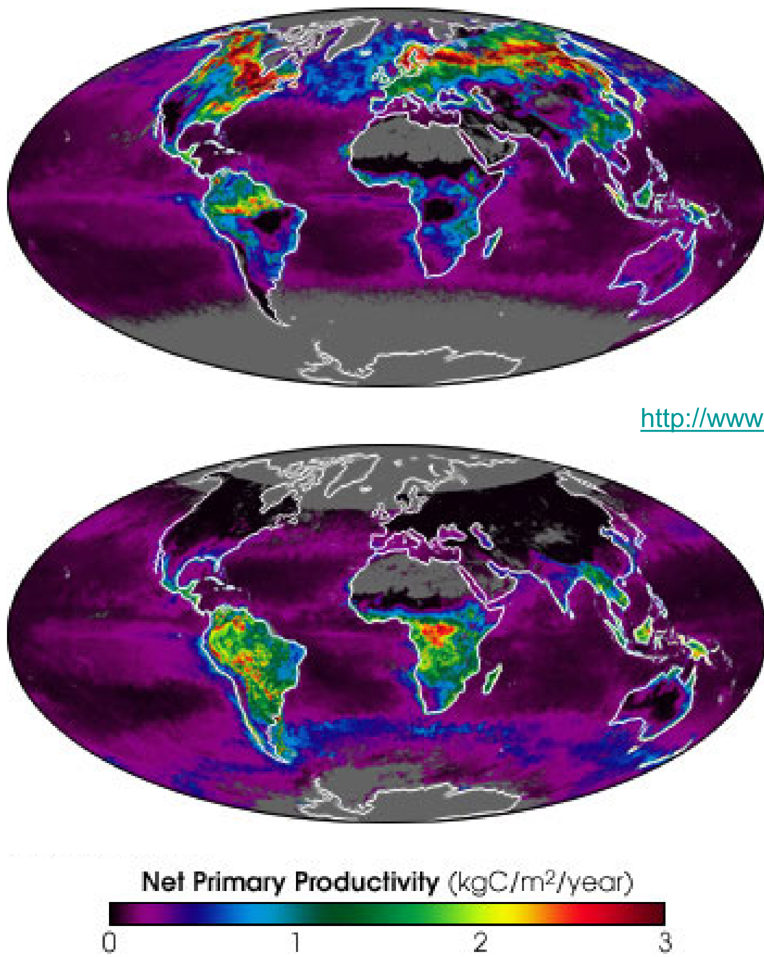
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$



Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Photosynthesis

- **Net primary productivity of organic matter:**
  $6\ CO_2 + 6\ H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6\ O_2$ is ~ 57×10^{15} g C yr^{-1}

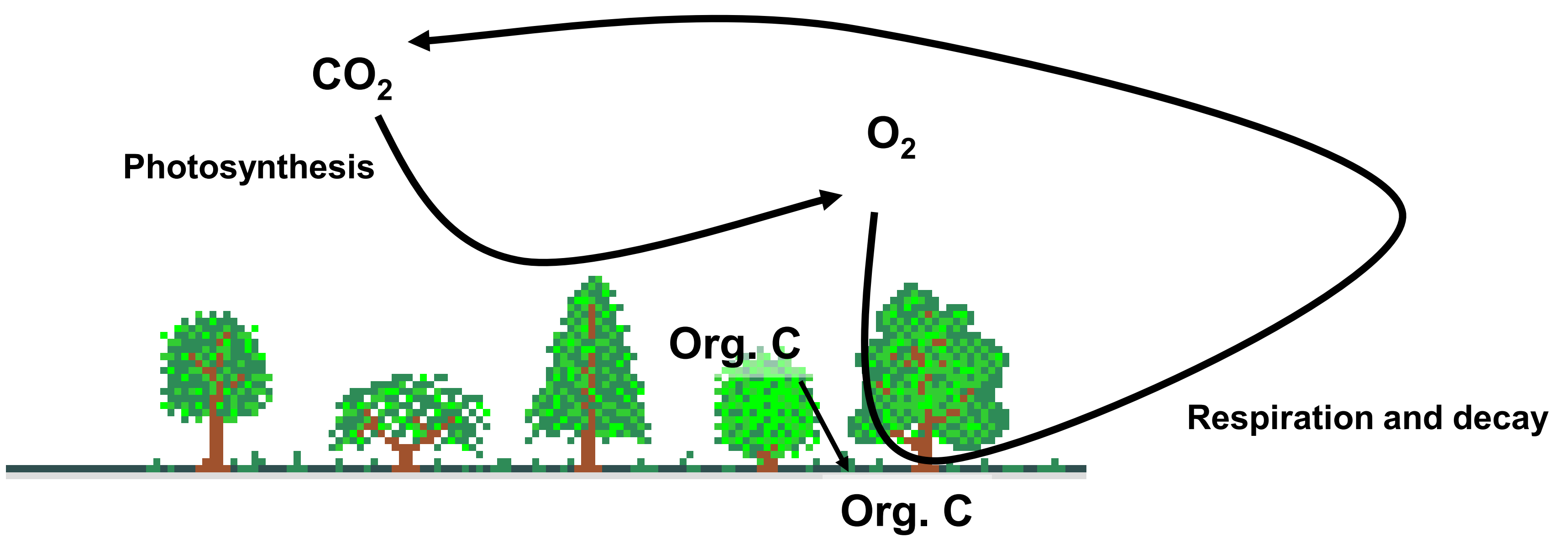
Imhoff *et al.*, *Nature*, 2004



http://www.globalcarbonproject.org/science/figures/FIGURE9.htm

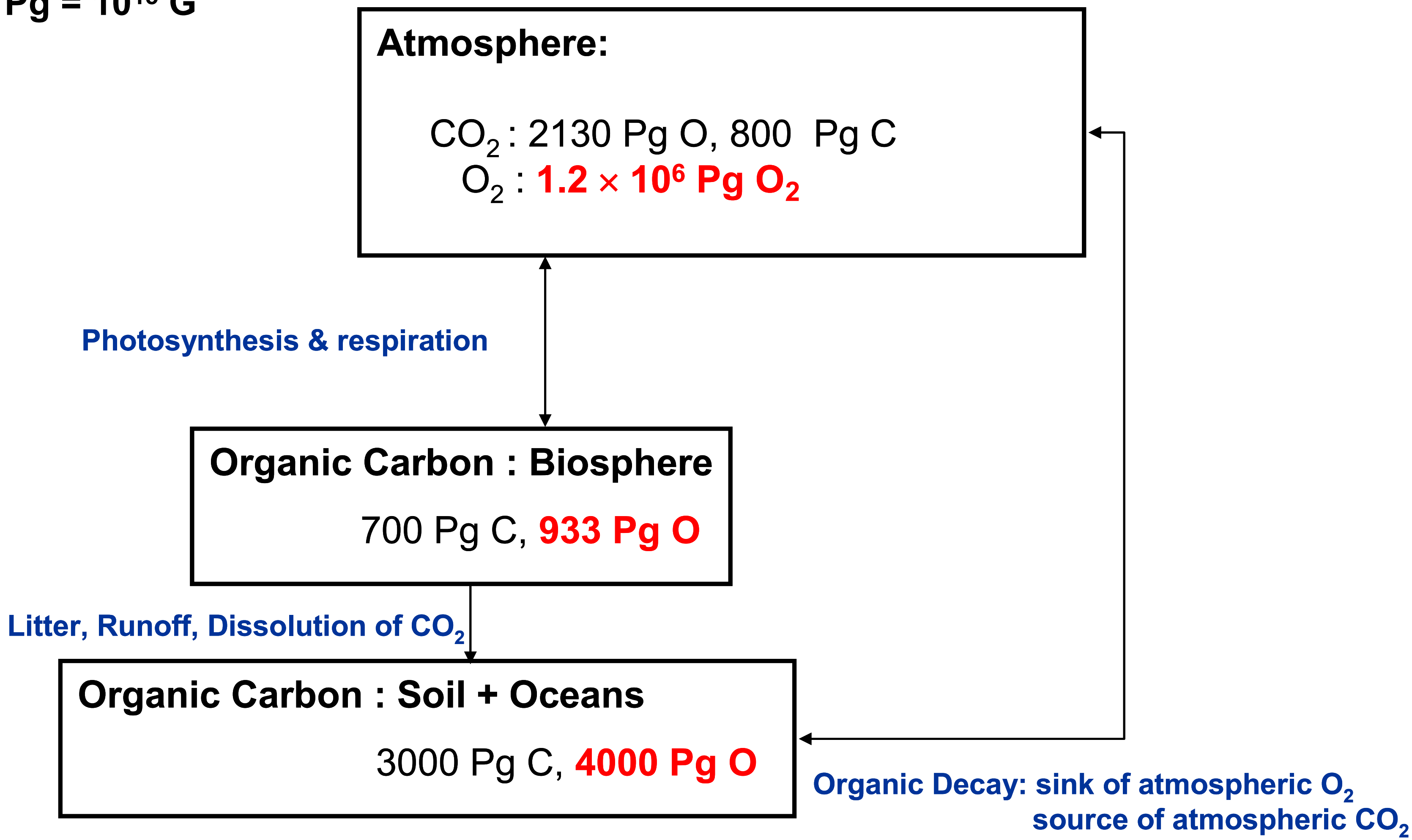
Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Photosynthesis

- **Net primary productivity of organic matter:**
  $6\ CO_2 + 6\ H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6\ O_2$ is ~ 57×10^{15} g C yr^{-1}
  Production of atmospheric O_2 is therefore $\boxed{\sim 152 \times 10^{15}\ \text{g}\ O_2\ yr^{-1}}$ Flux
- **Mass O_2 in atmosphere = $0.21 \times (5.2 \times 10^{21}$ g$) \times (32 / 28.8) \approx \boxed{1.2 \times 10^{21}\ \text{g}}$** Amount
- **Lifetime of atmospheric O_2 due to biology = Amount / Flux**



Geological Evolution of Earth's Atmosphere:
Oxygen and Carbon Reservoirs

1 Pg = 10^{15} G



Atmospheric O_2 reservoir much larger than O_2 content of biosphere, soils, and ocean; therefore, some *other process* must control atmospheric O_2

Geological Evolution of Earth's Atmosphere:
Oxygen Reservoirs & Pathways

1 Pg = 10^{15} G

Atmosphere:

O_2 : 1.2×10^6 Pg O_2

Burial of organic matter is source of atmospheric O_2:

$6CO_2 + 6\,H_2O + \text{Energy} \rightarrow$

$C_6H_{12}O_6$ (buried) + $6O_2$ (atmosphere)

O_2 Lifetime ≈ 4 million years

Sediments: Buried Organic Carbon

O_2 : ~32×10^6 Pg O

Weathering of mantle is sink of atmospheric O_2:

For example:

$FeS_2 + 7/2\,O_2 + H_2O \rightarrow Fe^{3+} + 2\,SO_4^{2-} + 2\,H^+$.

Crust and Mantle: Oxides of Fe, Si, S, Mg, etc:

FeO, Fe_2O_3, $FeSiO_3$, SiO_4, MgO, etc

This is where the bulk of the oxygen resides!

Geological Evolution of Earth's Atmosphere: *Atmospheric O_2 on Geological Time Scales*

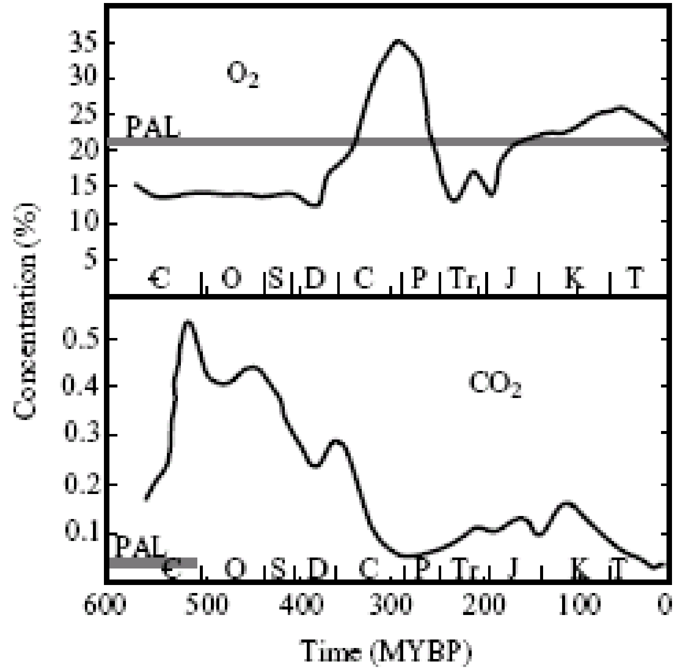
- **Rise of atmospheric O_2 linked to evolution of life:**
  - **400 My B.P. O_2 high enough to form an ozone layer**
  - **400 to 300 My B.P.: first air breathing lung fish & primitive amphibians**

- **On geological timescales, level of O_2 represents balance between burial of organic C & weathering of sedimentary material:**

  (see Chapter 12, "Evolution of the Atmosphere" in *Chemistry of the Natural Atmosphere* by P. Warneck (2nd ed) for an excellent discussion)

- **Present atmosphere is oxidizing:**

  $CH_4 \Rightarrow CO_2$ with time scale of ~9 years



From R. Dudley, Atmospheric O_2, Giant Paleozoic Insects, and the Evolution of Aerial Locomotor Performance, *J. Exper. Biol.*, 201, 1043, 1998.

Geological Evolution of Earth's Atmosphere: *Atmospheric CO_2 on Geological Time Scales*

~500 to 300 My B.P.

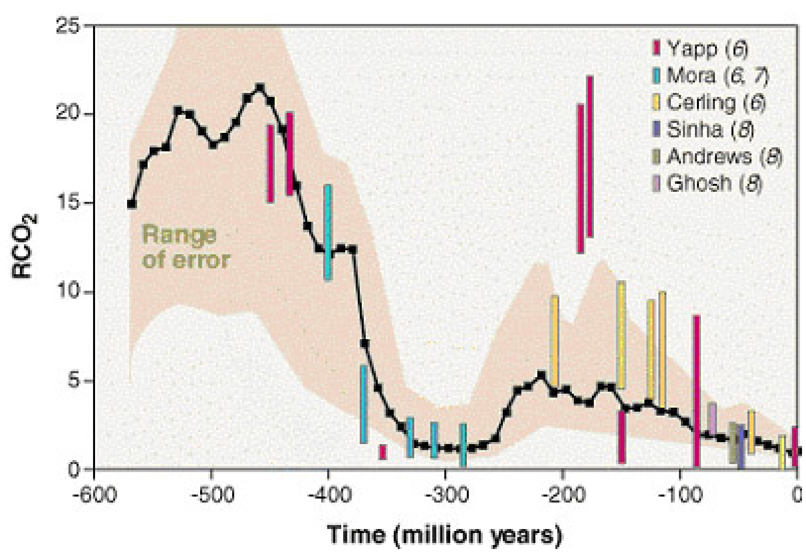
- **Development of vascular land plants**
- **Plants became bigger and bigger and less reliant on water**
- **Once buried, lignin in woody material resists decay**
- **Burial rate of terrestrial plant matter increases dramatically:**
  (evidence : $\delta^{13}C$ analysis)
- **Past burial rate of vascular plant material may have been much higher than present, due to the lack (way back when) of abundant bacteria, fungi, and small soil animals that now recycle plant matter**

Non-vascular: Bryophytes **Vascular: Pteridophytes**

Geological Evolution of Earth's Atmosphere: *Atmospheric CO_2 on Geological Time Scales*

~500 to 300 My B.P.

- **Development of vascular land plants**
- **Plants became bigger and bigger and less reliant on water**
- **Once buried, lignin in woody material resists decay**
- **Burial rate of terrestrial plant matter increases dramatically:**
  (evidence : $\delta^{13}C$ analysis)
- **Past burial rate of vascular plant material may have been much higher than present, due to the lack (way back when) of abundant bacteria, fungi, and small soil animals that now recycle plant matter**



From R. Berner, *Science,* 276, 544, 1997.

Geological Evolution of Earth's Atmosphere:
Precursors of Modern Day World

O_2 reaches current levels;
tree life flourishes;
animal life invades continents;
dinosaurs roam the Earth;
rise of Himalayas

N_2

CO_2

H_2O

oceans form

CO_2 dissolves

O_2

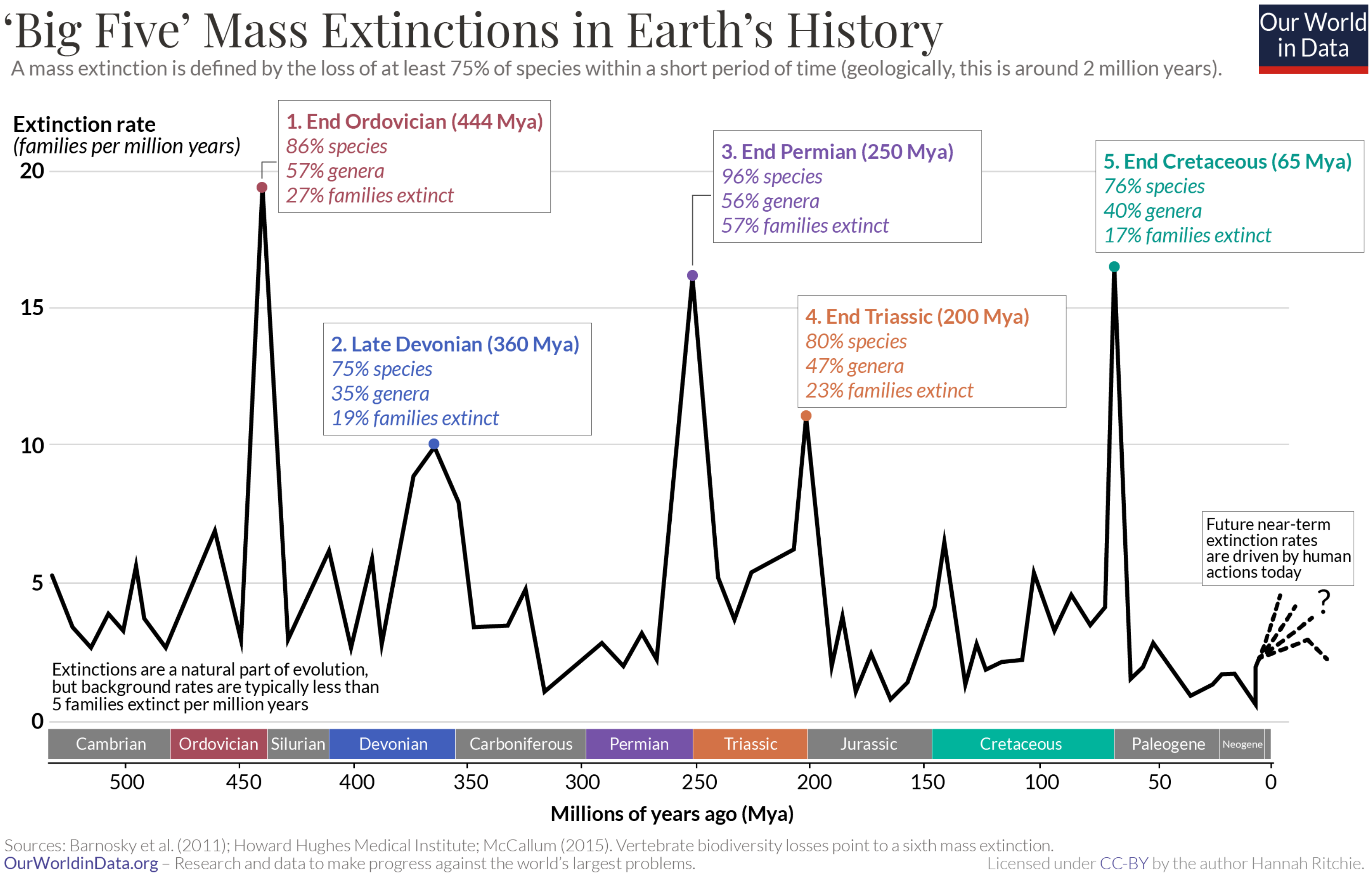
Outgassing

Life forms

Onset of photosynthesis

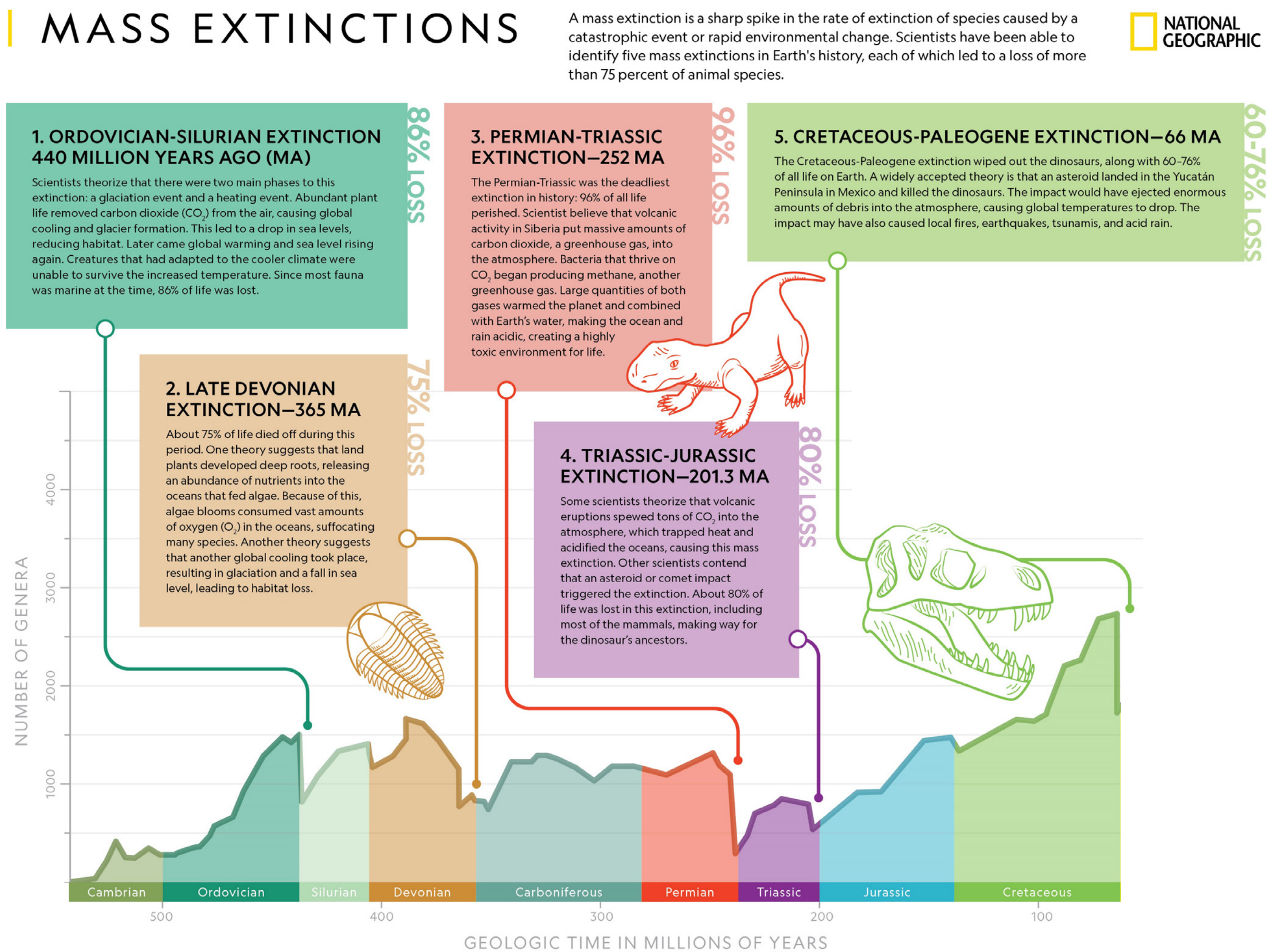
4.5 Gy before present | **4 Gy** | **3.5 Gy** | **0.4 Gy** | **present**

Geological Evolution of Earth's Atmosphere:
Earth Has Endured Five Major Extinctions



https://ourworldindata.org/mass-extinctions

Geological Evolution of Earth's Atmosphere:
Atmospheric CO_2 Thought to be Causal Factor in 4 of the 5



https://www.geologyin.com/2017/08/an-overview-of-earths-major-mass.html

Geological Evolution of Earth's Atmosphere: CO_2 and Temperature

What message were we trying to convey?

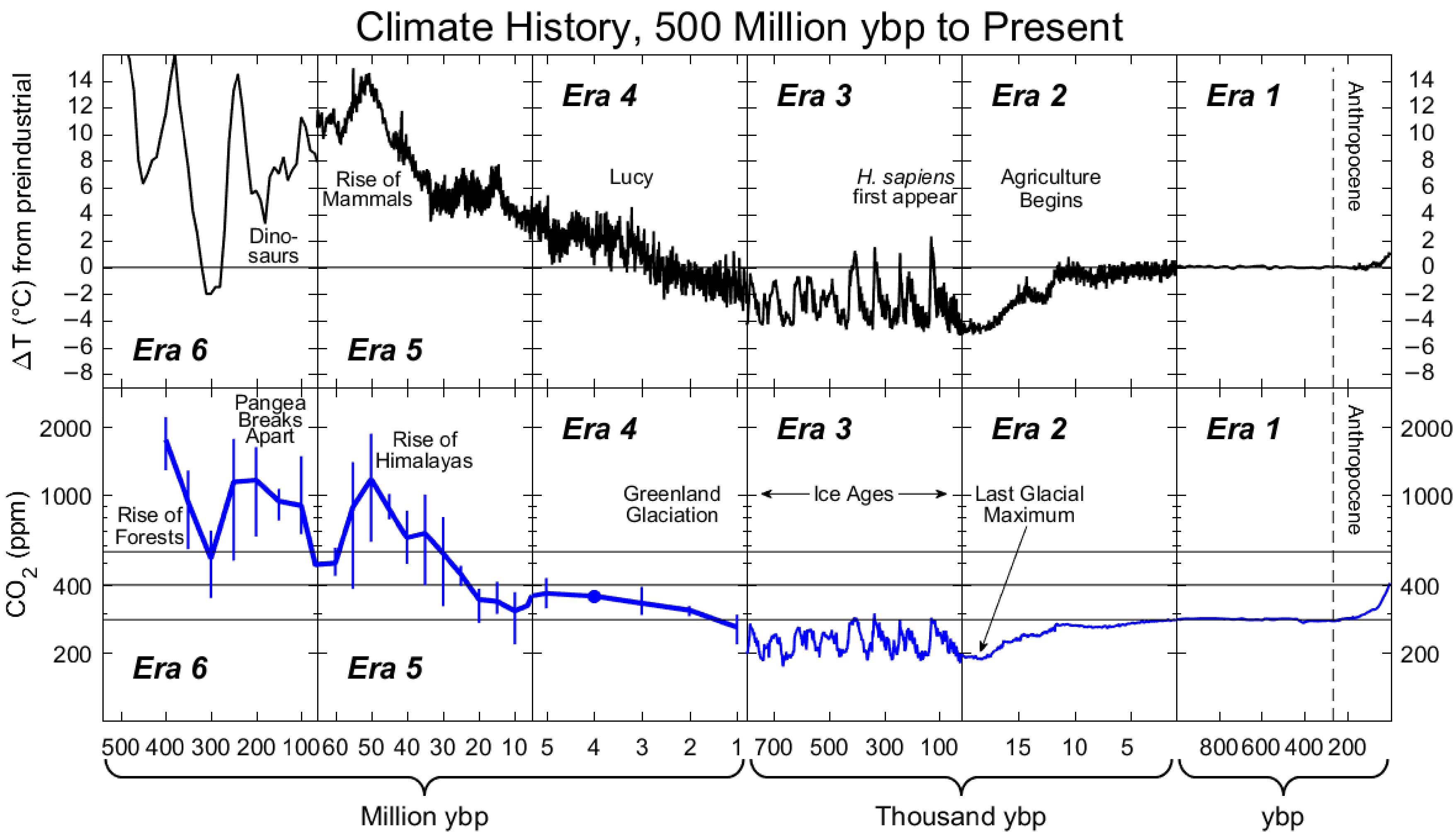
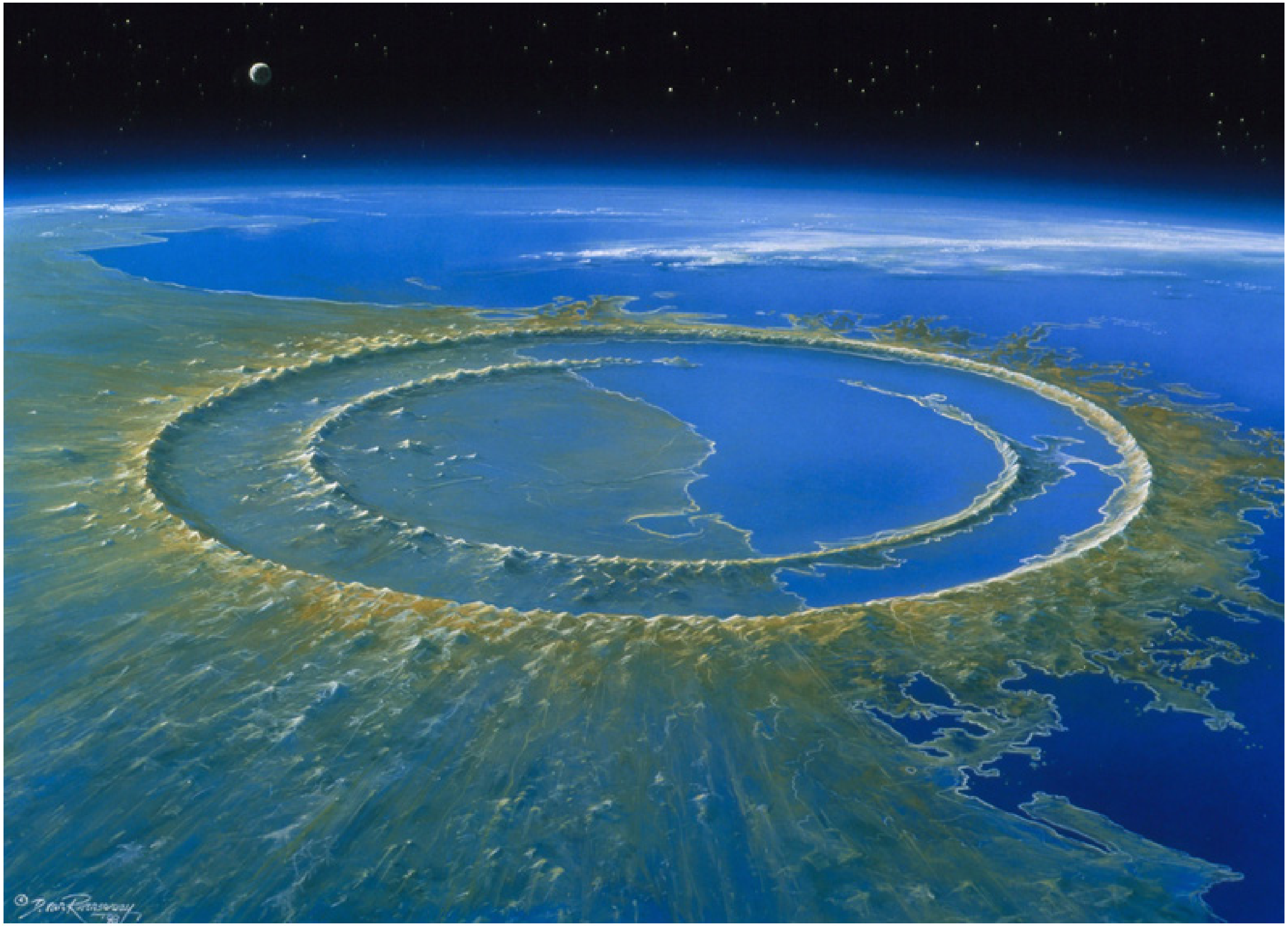


Fig 1.1, *Paris Beacon of Hope*

Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***



An artist's impression of what the Chicxulub crater might have looked like soon after an asteroid struck the Yucatán Peninsula in Mexico. Researchers studied the peak rings, or circular hills, inside the crater. Detlev van Ravenswaay/Science Source

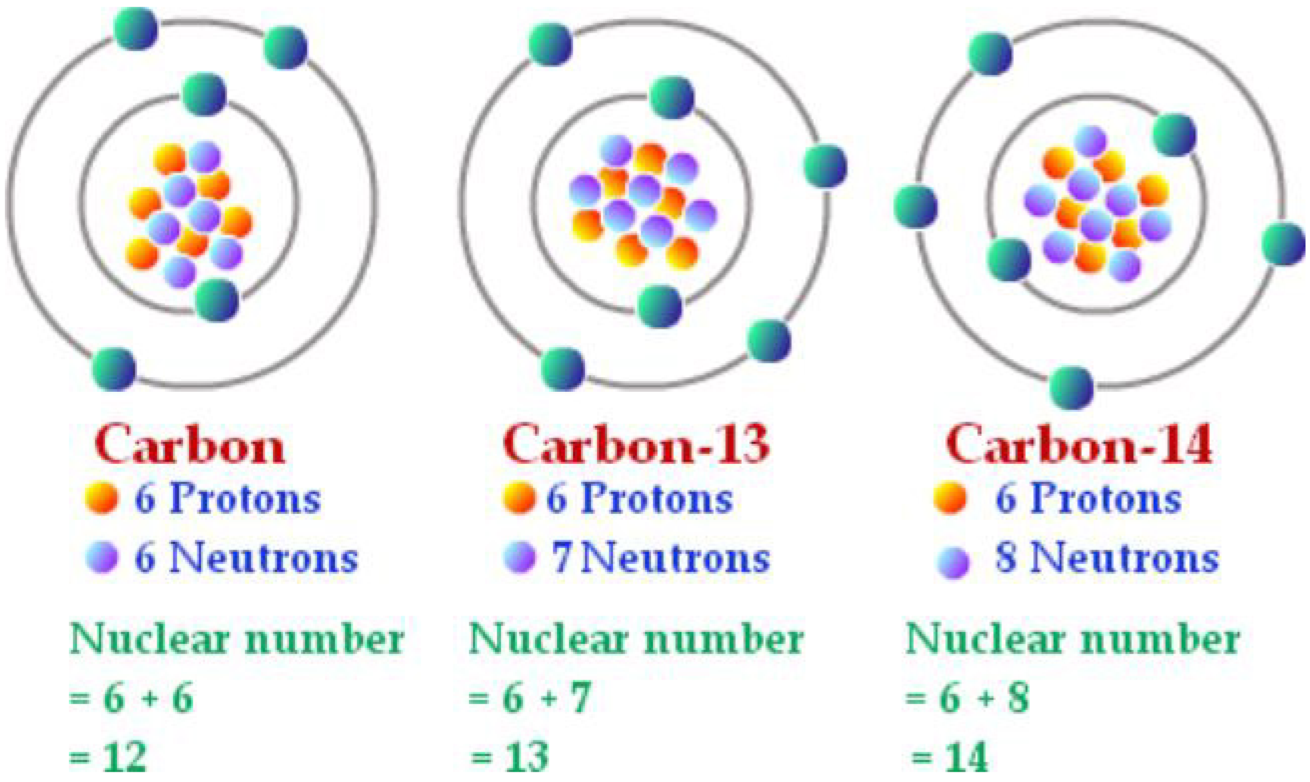
https://www.nytimes.com/2016/11/18/science/chicxulub-crater-dinosaur-extinction.html

Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***

https://www.dailymotion.com/video/x6d8tba
We'll look at about 34:50 to 38:50

Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***

Biology prefers light forms of carbon:



https://experiment.com/u/iA41fA

Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***

By understanding how the carbon isotopic ratio of the world's surface waters changed at the K-T boundary, as recorded by the shells of preserved oceanic organisms, we could compute the fraction of the world's biosphere that must have burned on this really bad day (or soon thereafter):

Carbon isotopic evidence for biomass burning at the K-T boundary

A new interpretation of existing carbon isotopic data combined with results from a biogeochemical model suggests that burning of terrestrial biomass occurred on a global scale at the Cretaceous-Tertiary (K-T) boundary. Carbon isotopic ratios from planktonic and benthic microfossils across the K-T boundary reveal not only a breakdown in the normal surface-water to deep-water gradient of $^{13}C/^{12}C$, but also a reversal at the boundary. This reversal cannot be explained by the cessation of primary production alone. We propose that combustion of terrestrial biomass with subsequent transfer of isotopically light carbon to surface waters is the most likely cause of this anomaly. A biogeochemical model is used to quantify the extent of burning at the boundary: combustion of roughly 25% of the above-ground biomass at the end of the Cretaceous is necessary to account for the observed isotopic signal.

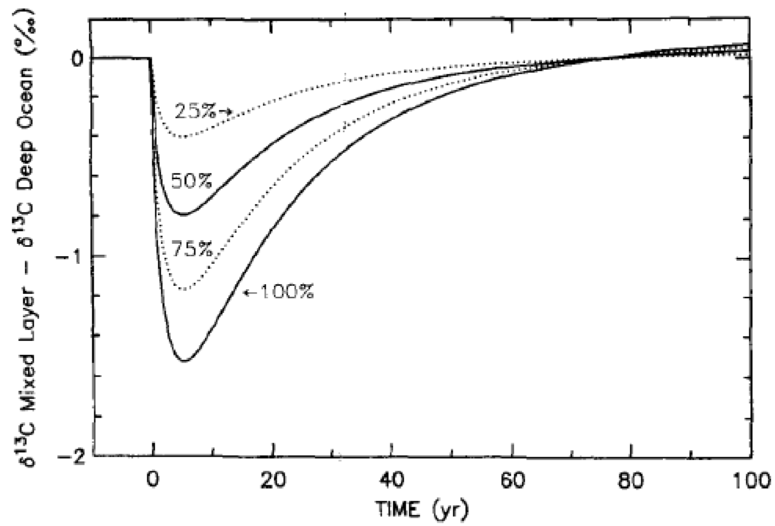


Figure 2. Variation of surface-water to deep-water gradient of $\delta^{13}C$ vs. time for simulations of biomass combustion, assumed to occur instantaneously at time zero. Results are shown for burning 25%, 50%, 75%, and 100% of above-ground biomass (10^{18} g C; $\delta^{13}C = -25.7‰$) at end of Cretaceous assuming combustion efficiency of 50% (i.e., model result for 100% combustion corresponds to injection of half of above-ground biomass carbon into atmosphere as CO_2 at time zero).

Ivany and Salawitch, *Geology*, 1993
Link to this paper appears in auxiliary reading for today's class

Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***

By understanding how the carbon isotopic ratio within the bodies of fish recovered at the impact site, scientists have determined the impact Occurred during boreal (NH) spring:

The Mesozoic terminated in boreal spring

The Cretaceous–Palaeogene mass extinction around 66 million years ago was triggered by the Chicxulub asteroid impact on the present-day Yucatán Peninsula[1,2]. This event caused the highly selective extinction that eliminated about 76% of species[3,4], including all non-avian dinosaurs, pterosaurs, ammonites, rudists and mos marine reptiles. The timing of the impact and its aftermath have been studied mainly on millennial timescales, leaving the season of the impact unconstrained. Here, by studying fishes that died on the day the Mesozoic era ended, we demonstrate that the impact that caused the Cretaceous–Palaeogene mass extinction took place during boreal spring. Osteohistology together with stable isotope records of exceptionally preserved perichondral and dermal bones in acipenseriform fishes from the Tanis impact-induced seiche deposits[5] reveal annual cyclicity across the final years of the Cretaceous period. Annual life cycles, including seasonal timing and duration of reproduction, feeding, hibernation and aestivation, vary strongly across latest Cretaceous biotic clades. We postulate that the timing of the Chicxulub impact in boreal spring and austral autumn was a major influence on selective biotic survival across the Cretaceous–Palaeogene boundary.

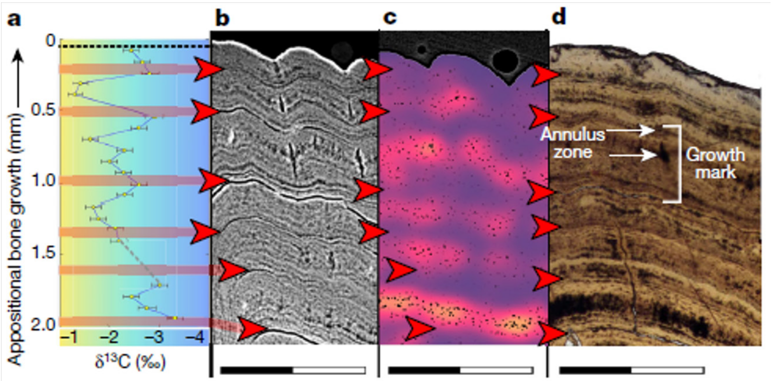


Fig. 3 | Carbon isotope record alongside the incremental growth profiles across the dentary of paddlefish VUA.GG.2017.X-2724. a, δ

During et al., *Nature*, 2022
Link to this paper appears in auxiliary reading for today's class

Geological Evolution of Earth's Atmosphere: CO_2 and Temperature

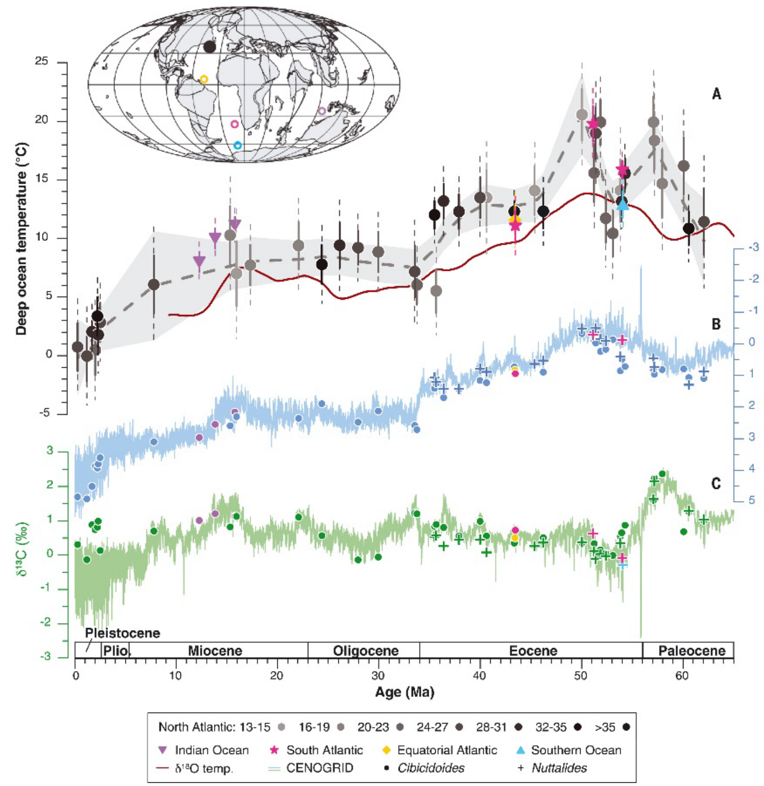
Scientists are still debating important details of Figure 1.1: using isotopes!

A hotter greenhouse?

Comparing these new temperatures to the CO_2 levels prevalent at the time produced a bit of a surprise. "Perhaps most striking is the evidence this study provides for tight coupling between geologically brief periods of high CO_2 and deep ocean temperature," said John Eiler of Caltech, who pioneered the use of clumped isotopes to measure ancient temperatures but was not part of Meckler's study.

The IPCC's best estimate is that doubling our CO_2 from preindustrial levels will result in 3°C of global warming, but the uncertainty remains large—it could be between 2.5°C and 4°C for that same increase in CO_2. If the value is closer to 4ºC, Earth will warm more for the same amount of CO_2 in the air. Meckler's warmer temperatures suggest that CO_2's capacity to warm during that time in Earth's past was higher than was found in earlier studies. "This would lead to a higher climate sensitivity to atmospheric CO_2," the paper says.

Alternatively, reconstructions of atmospheric CO_2 levels at the time may underestimate those past gas concentrations. "There's quite a lot of uncertainty still in the CO_2 reconstructions," Meckler said. She also noted that the researchers don't yet have global coverage with their data. "I do want to want to put a caveat here that we have only looked at the Atlantic Ocean so far, so it could be that the Atlantic Ocean is doing something special," Meckler told Ars. "This increased sensitivity to CO_2 would only be the case if this was really a global signal—we don't know that yet."



Meckler *et al.*, *Science*, 2022
See also Auderset *et al., Nature*, 2022

https://arstechnica.com/science/2022/08/ancient-deep-ocean-may-have-been-hotter-than-we-thought/

Geological Evolution of Earth's Atmosphere: *Human Influence*

N_2

CO_2

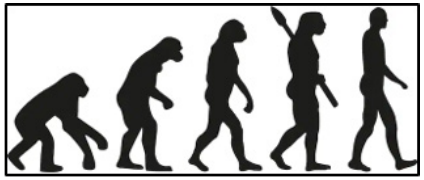
H_2O

oceans form

CO_2 dissolves

O_2

Rise of mammals
(65 million ybp)
Evolution of homo sapiens
Invention of agriculture
Industrialization



Outgassing

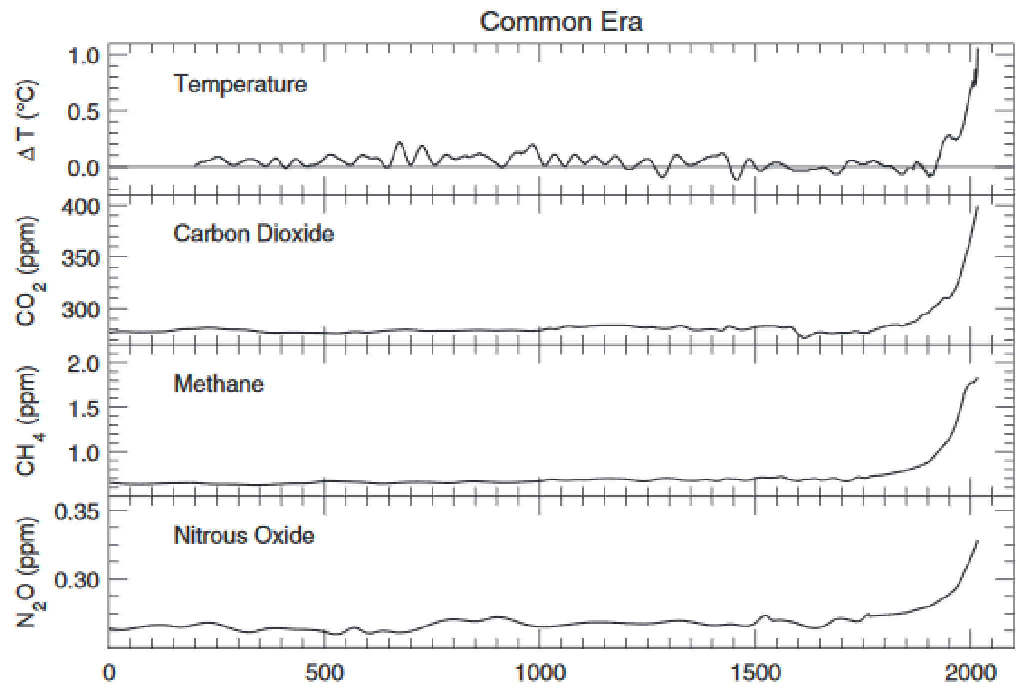
Life forms

Onset of photosynthesis

4.5 Gy before present | **4 Gy** | **3.5 Gy** | **0.4 Gy** | **present**

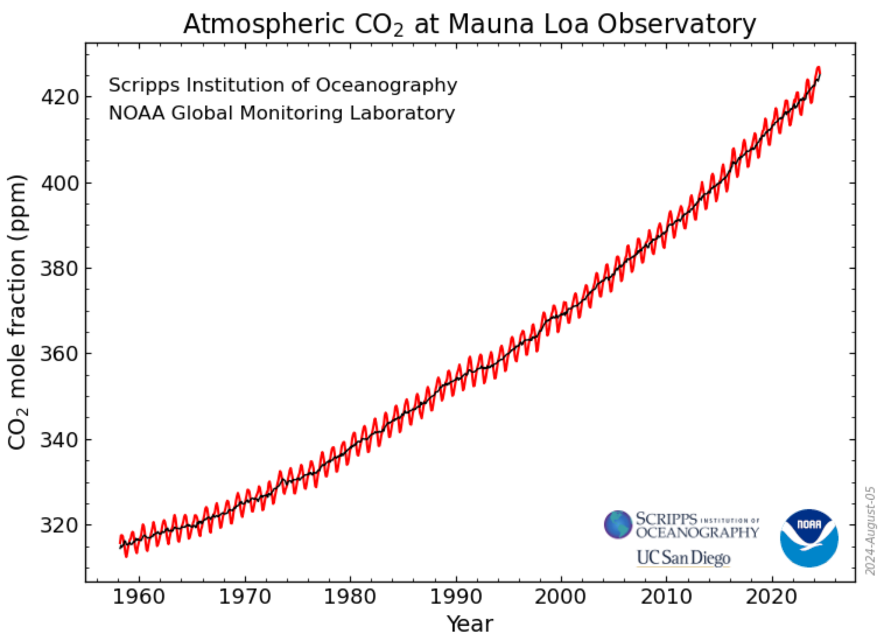
Geological Evolution of Earth's Atmosphere: *Human Influence*

What message were we trying to convey?



Earth's Atmosphere – Effect of Humans

CO_2: ~420 parts per million (ppm) and rising !



Charles Keeling, Scripps Institution of Oceanography, La Jolla, CA
https://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.png

Human drivers of global warming over the last millennium

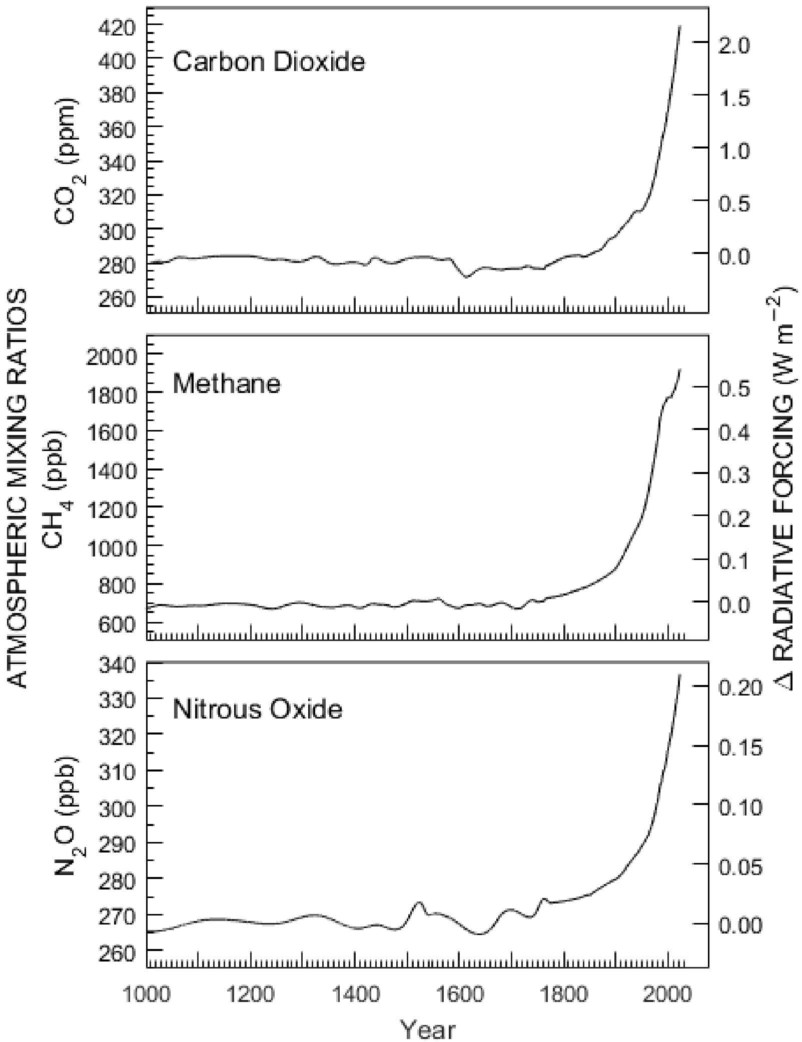


Figure courtesy Brian Bennett, Univ of Md

Geological Evolution of Earth's Atmosphere: *Human Influence*

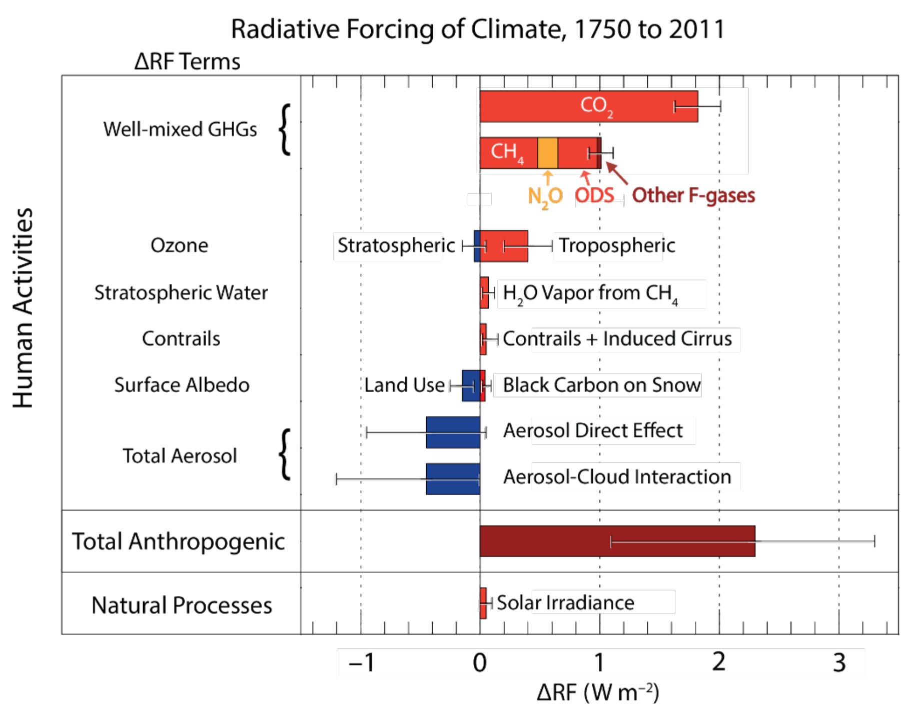
Question 3 -- / 4 pts

Based on Figure 1.4 and the text that describes this figure:

a) estimate quantitatively how well scientists know the total RF of climate due to CO_2, CH_4, N_2O, ODS, and other F-Gases over 1750 to 2011, being sure to comment on the uncertainty of this term

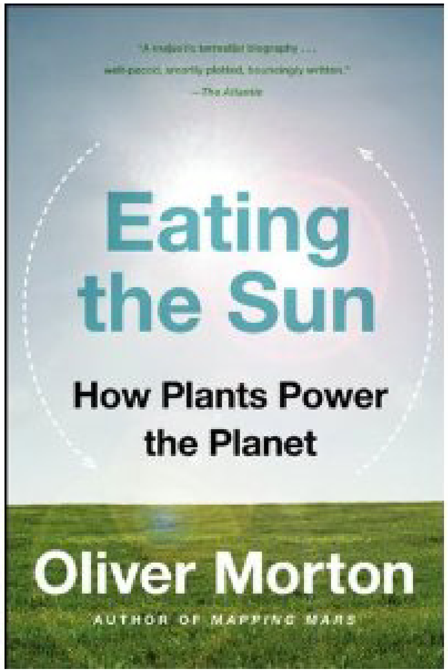
b) estimate quantitatively how well scientists know the total RF of climate due to tropospheric aerosols, again over 1750 to 2011, also being sure to comment on the uncertainty of this term

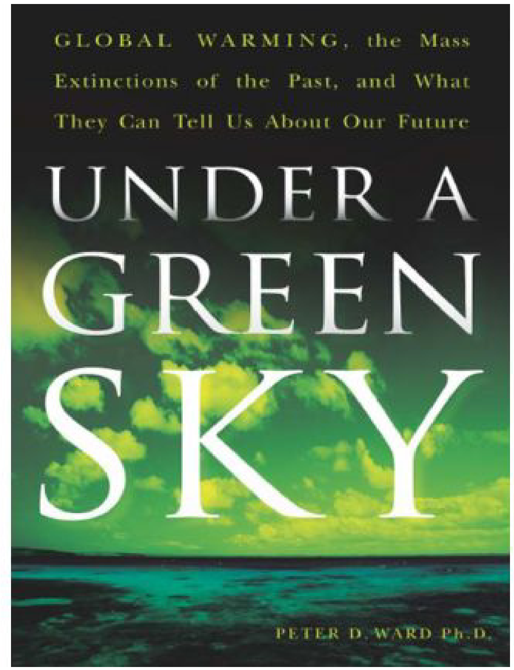
c) compare the uncertainty for the warming due to GHGs [that is, the uncertainty found for part a)] to the uncertainty for the cooling due to tropospheric aerosols [that is, the uncertainty found in part b)] and speculate whether or not you think the magnitude of these respective uncertainties might pose a problem for scientific understanding of global warming.



Source Material

These books are a great resource for how photosynthesis works as well as the history of atmospheric composition





http://www.amazon.com/Eating-Sun-Plants-Power-Planet/dp/0007163657/ref=sr_1_1?s=books&ie=UTF8&qid=1359325940&sr=1-1&keywords=eating+the+sun

http://www.amazon.com/Under-Green-Sky-Warming-Extinctions/dp/0061137928/ref=sr_1_1?s=books&ie=UTF8&qid=1359326345&sr=1-1&keywords=under+a+green+sky

and provided some of the source material for much of this lecture

Next Lecture: Overview of Global Warming

2. Schedule

Date	Lecture Topic	Required Reading	Admis. Tickets	Lecture Notes	Problem Sets	Additional Readings	Learning Outcome
08/27	Class Overview	No reading for first meeting	No AT	Lecture 0 Video			No Quiz
08/29	Geological Evolution of Earth's Atmosphere	Paris Beacon of Hope Sec 1.1, 1.2 (intro), and 1.2.1 (11.5 pages)	AT 1	Lecture 1 Video		Meckler *et al.*, *Science*, 2022 Excellent news article on Meckler *et al.* study Ivany and Salawitch, *Geology*, 1993 NOVA: The Day The Dinosaurs Died BBC Article, Life on Mars Webster et al., *Science*, 2014	Quiz 1
09/03	Overview of Global Warming	Climate Change Evidence and Causes, Royal Society (36 pages) IPCC 2007 FAQ (1.1, 1.2, 1.3, 2.1, & 3.1) (11 pages) Paris Beacon of Hope Sec 1.2.2 (3 pages)	AT 2	Lecture 2 Video		Kerr, *Science*, 2007 Warming Animation ENSO Video Entire IPCC 2007 FAQ News story 1, Antarctic Ice News Story 2, Antarctic Glacier	Quiz 2

Readings: Royal Society Report (36 pages of easy, breezy reading)
IPCC 2007 FAQ 1.1, 1.2, 1.3, 2.1, & 3.1 (11 pages; harder reading)
Paris Beacon of Hope, Sect 1.2.2 (3 pages with a most important equation)

Admission Ticket for Lecture 2 is now posted on ELMS-Canvas

https://www2.atmos.umd.edu/~rjs/class/fall2024