Geologic Evolution of Earth's Atmosphere

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2020
https://myelms.umd.edu/courses/1291919

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

Lecture 1

3 September 2020

Announcements

1) New student introductions

2) AOSC Weekly Seminar Sept 3: 3:30 pm (today!)

DR. MORGAN O'NEILL

INSTITUTION: EARTH SYSTEM SCIENCE, STANFORD UNIVERSITY

TITLE: FUJITA'S "JUMPING CIRRUS:" HYDRAULIC JUMP DYNAMICS ABOVE SUPERCELL THUNDERSTORMS

Abstract: The strongest supercell thunderstorms typically feature an Above-Anvil Cirrus Plume (AACP), which is a wake of ice and water vapor downstream of overshooting deep convection, several km above the large anvil shield. Thunderstorms are known to be an important source of water vapor to the lower stratosphere, with substantial implication for climate. Previous work has shown that the occurrence of the AACP is coincident with strong evidence of breaking gravity waves, but a more detailed study of its dynamics and lifecycle has not been undertaken. Using 50-m isotropic large eddy simulations, we show that the overshooting top of a supercell acts as a topographic obstacle and drives a hydraulic jump downstream. Stratospheric air that crests the effective topography plummets smoothly down the lee side at speeds exceeding 100 m/s and then quickly transitions to highly turbulent in a rapidly-evolving hydraulic jump. This jump injects water vapor and ice into the lower stratosphere irreversibly, several kilometers above the top of the anvil cloud, forming a distinct, realistic AACP. We provide the first study of a large-scale hydraulic jump in the absence of solid topography.

Morgan received her B.S. in Physics at the University of New Hampshire in 2009 and her Ph.D. in Atmospheric Sciences at MIT in 2015 working with Dr. Kerry Emanuel. She was a Koshland Prize Postdoctoral Fellow at the Weizmann Institute of Science and then a T. C. Chamberlin Fellow at the University of Chicago before joining the Earth System Science faculty at Stanford in 2018. She is also currently a Center Fellow, by courtesy, of the Stanford Woods Institute for the Environment, and a Gabilan Faculty Fellow.

Zoom Link: https://umd.zoom.us/j/94562248135?pwd=TElyVS9TY0ZTSTZZNU01L0F1eTdTZz09

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

Date	Lecture Topic	Required Reading	Admis. Tickets	Lecture Notes	Problem Sets*	Additional Readings	Learning Outcome
09/01	Class Overview	No reading for first meeting	No AT	Lecture 0 2020 Zoom Video			No Quiz
09/03	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 2020 Zoom Video		https://www.pbs.org/wgbh/nova/video/day-the-dinosaurs-died Ivany and Salawitch, *Geology*, 1993	Quiz 1
09/08	Overview of Global Warming, Air Quality, & Ozone Depletion	IPCC 2007 FAQ (1.1, 1.2, 1.3, 2.1, & 3.1) (11 pages) EPA AQI Brochure (11 pages) 20 QAs Ozone (Q1, 2, 7, & 14) (11 pages) Paris Beacon of Hope Sec 1.2.2 (3 pages)	AT 2	Lecture 2 2020 Zoom Video		Kerr, *Science*, 2007 * Bell *et al.*, *EHP*, 2006 * Montzka *et al.*, *Nature*, 2018 Naming Convention for CFCs & Halons Entire IPCC 2007 FAQ Entire 20 QAs Ozone Movie Clip	Quiz 2

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4) Anyone else?

Announcements

Today's lecture:

Next Tuesday:

Announcements

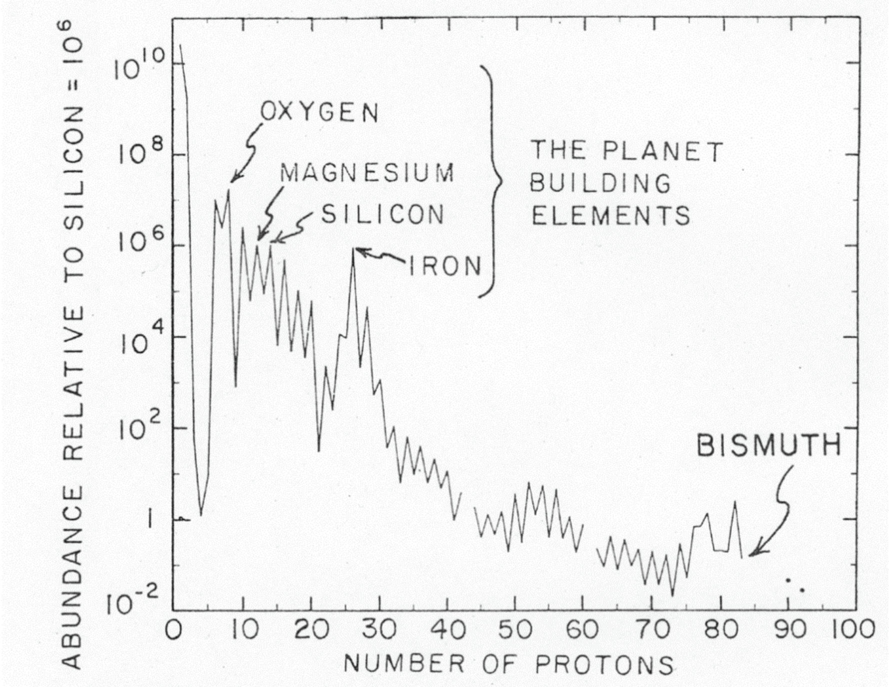
Next Thursday:

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**

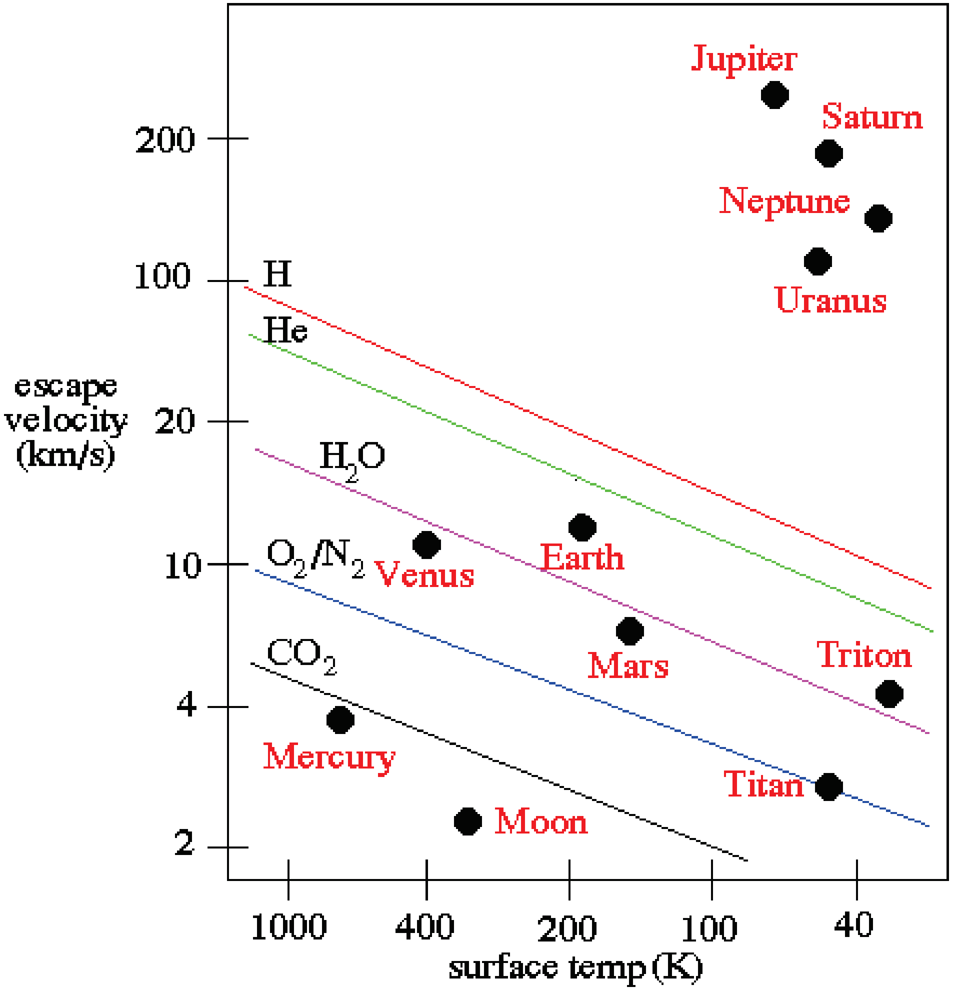


From "How to Build a Habitable Planet"
By W.S. Broecker, ELDIGIO Press, pg 57

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:

Earth is of course the water planet
The source of Earth's water has been unclear

A new study finds that Earth's water may have come from materials that were present in the inner solar system at the time the planet formed – instead of far-reaching comets or asteroids delivering such water. The findings published 28 Aug 2020 in Science suggest that Earth may have always been wet.

"Our discovery shows that the Earth's building blocks might have significantly contributed to the Earth's water," said lead author Laurette Piani. "Hydrogen-bearing material was present in the inner solar system at the time of the rocky planet formation, even though the temperatures were too high for water to condense."

The findings from this study are surprising because the Earth's building blocks are often presumed to be dry. They come from inner zones of the solar system where temperatures would have been too high for water to condense and come together with other solids during planet formation.

Enstatite chondrites have similar oxygen, titanium and calcium isotopes as Earth, and this study showed that their hydrogen and nitrogen isotopes are similar to Earth's, too. In the study of extraterrestrial materials, the abundances of an element's isotopes are used as a distinctive signature to identify where that element originated.

Press release: https://source.wustl.edu/2020/08/meteorite-study-suggests-earth-may-have-always-been-wet
Paper: https://science.sciencemag.org/content/369/6507/1110

Geological Evolution of Earth's Atmosphere:
Elon Musk and Mars

SEPTEMBER 1ST 20__VICTOR TANGERMANN__FILED UNDER: OFF WORLD

Almost Inhabitable

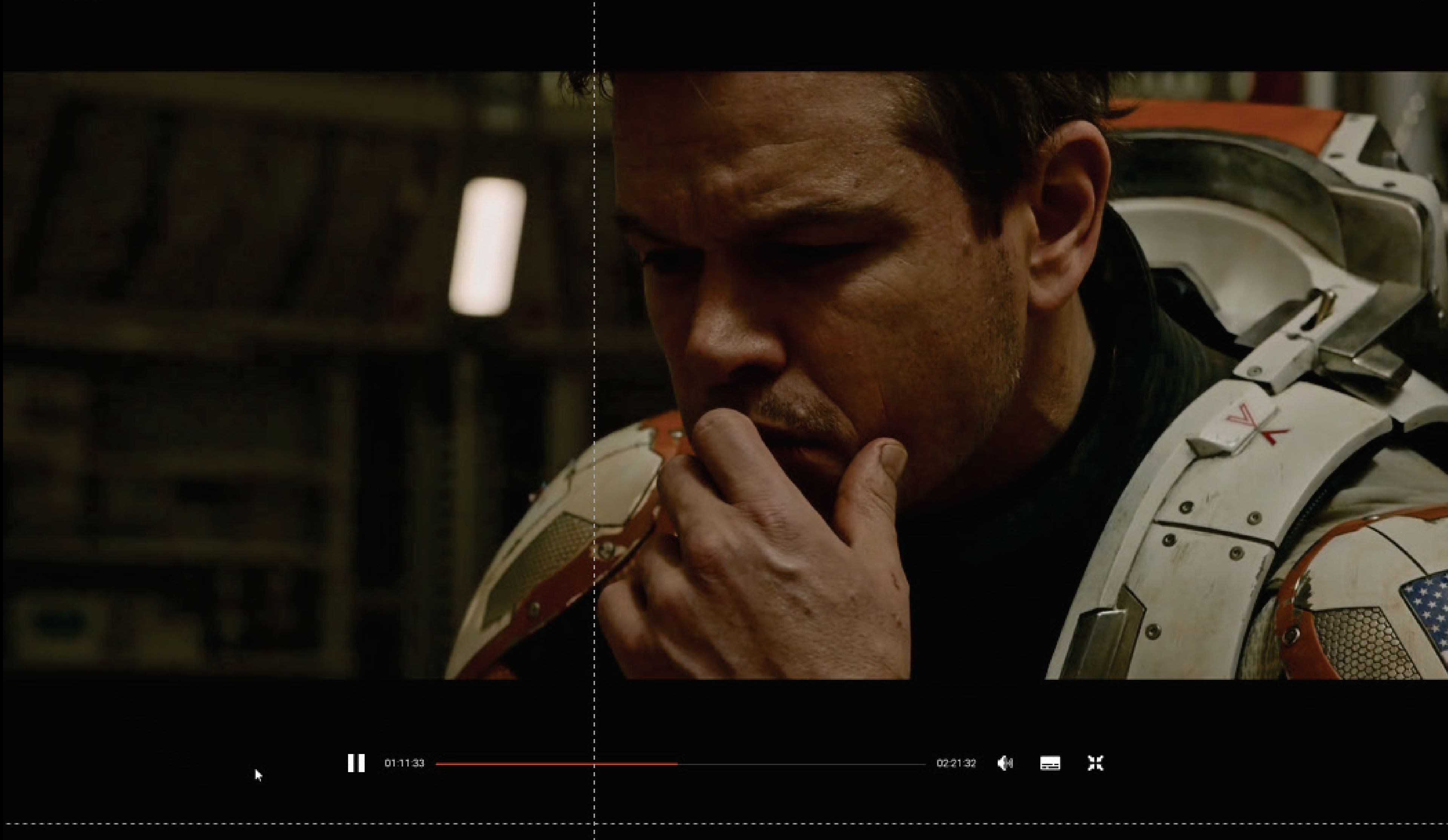
During Monday's virtual Humans to Mars summit, SpaceX CEO Elon Musk elaborated on his grand ambitions of building a self-sustaining city on Mars by the year 2050 — and the potential dangers settlers will face in the construction of such an extraplanetary civilization.

"Getting to Mars, I think, is not the fundamental issue," he said during the event, as quoted by *CNBC*. "The fundamental issue is building a base, building a city on Mars that is self-sustaining."

"I want to emphasize, this is a very hard and dangerous and difficult thing," he added. "Not for the faint of heart. Good chance you'll die. And it's going to be tough, tough going, but it'll be pretty glorious if it works out."

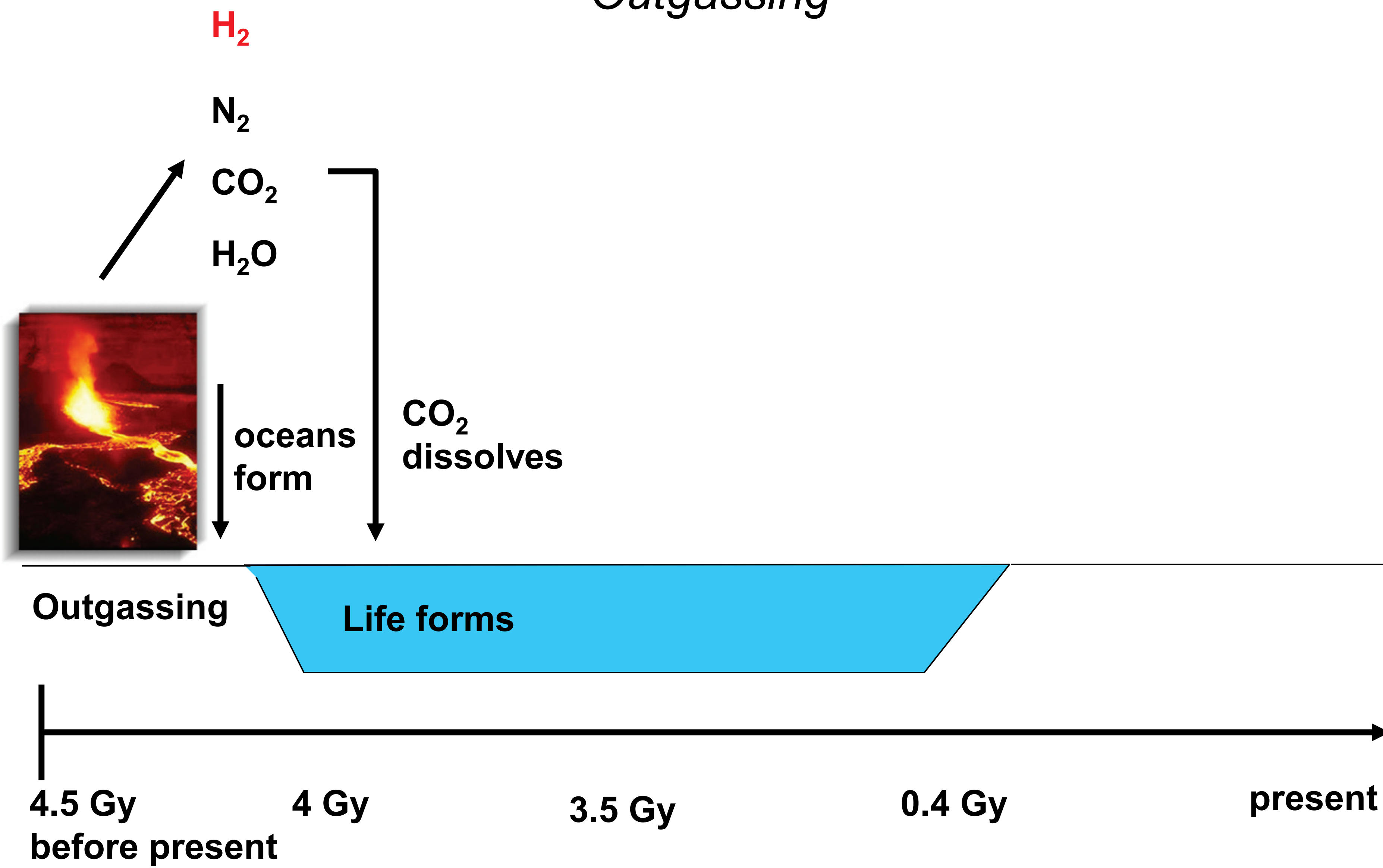
https://futurism.com/the-byte/elon-musk-die-on-mars-city-starship

The Martian



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

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**

→

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

How do we know early atmosphere was reducing ?

Why was a reducing environment important ?

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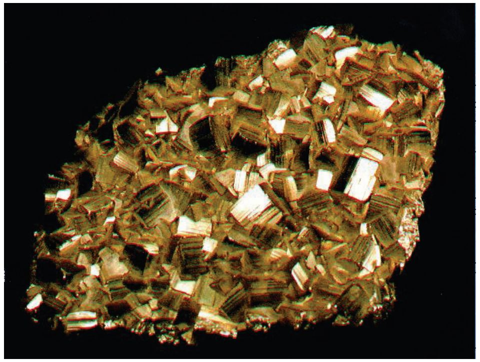

Minerals such as pyrite (iron sulfide),or "fools gold", are unstable in oxidizing environments and are found only in early deposits

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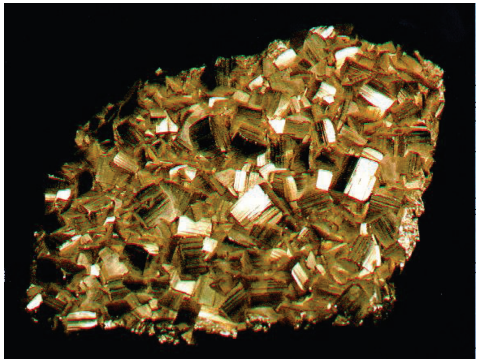

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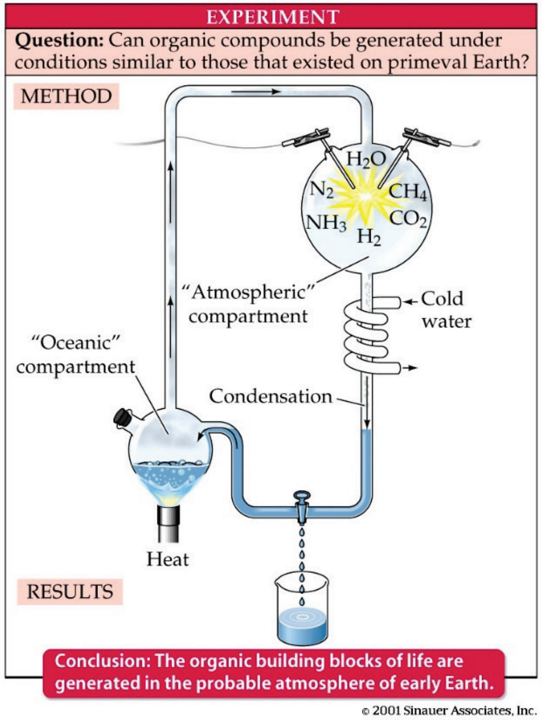
Why was a reducing environment important ?

Organic molecules produced from sparking a mixture of CH_4, NH_3, H_2O and H_2 :

Miller & Urey, "Organic compound synthesis on early Earth", Science, 1959



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

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The rise of atmospheric oxygen led to something else critical to "life as we know it" − what did rising [O_2] lead to ?!?

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

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

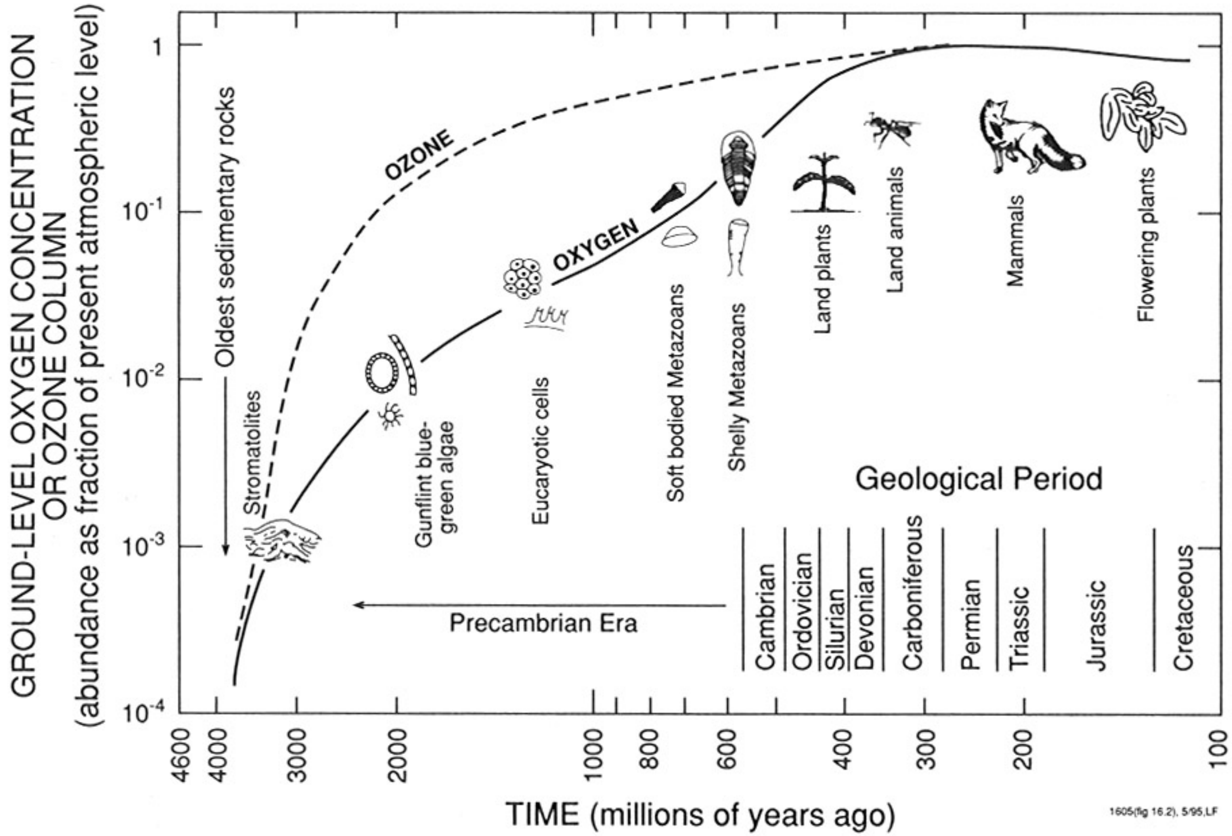


Figure 16.3. *Probable evolution of the oxygen and ozone abundance in the atmosphere (fraction of present levels) during the different geological periods of the Earth's history (Wayne, 1991; reprinted by permission of Oxford University Press).*

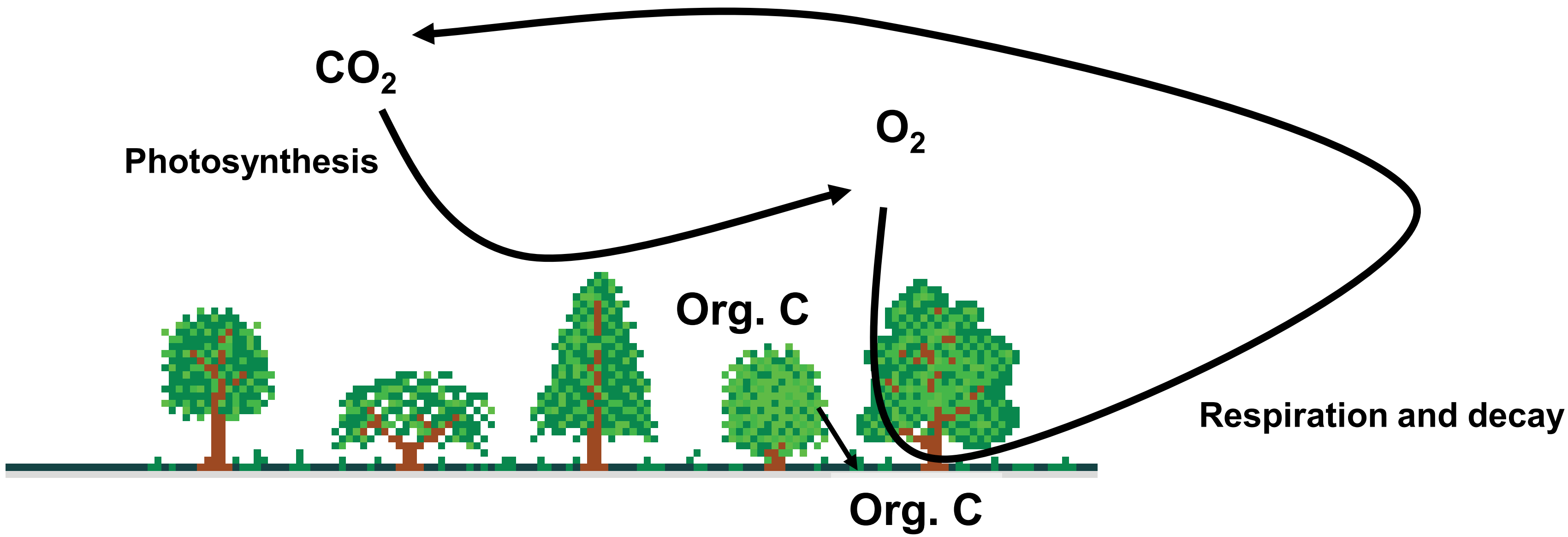
Geological Evolution of Earth's Atmosphere:
Early Atmosphere: Photosynthesis

- **Photosynthesis: Source of O_2**

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

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

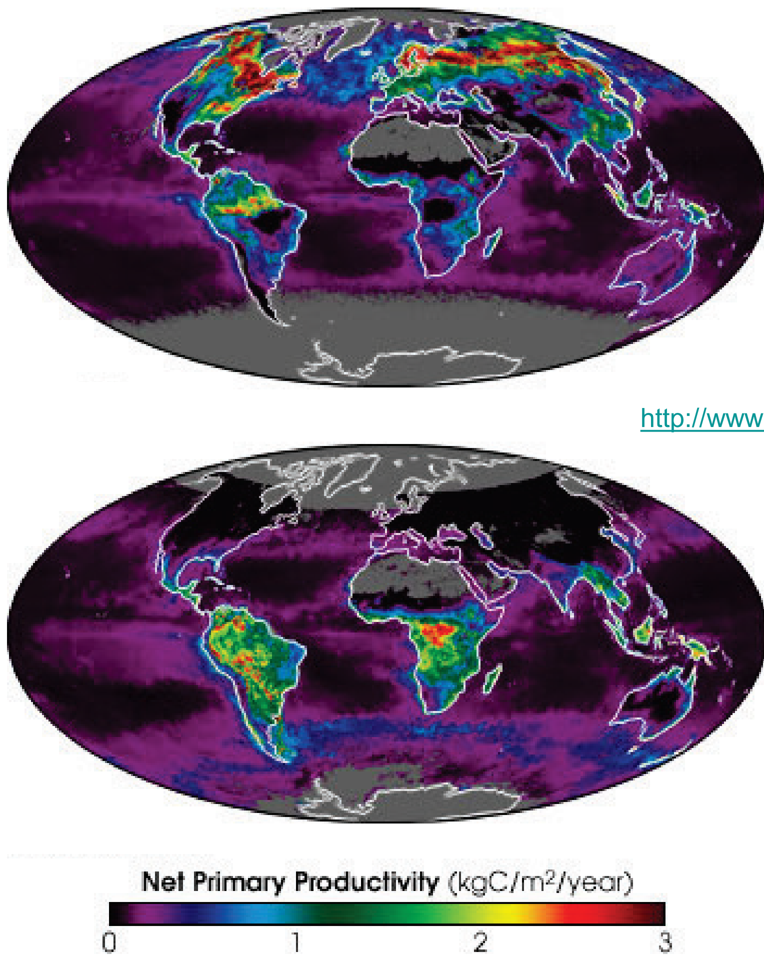
$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$



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

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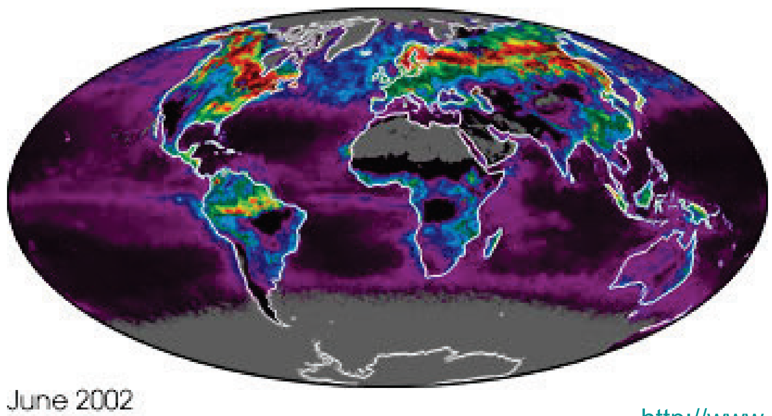

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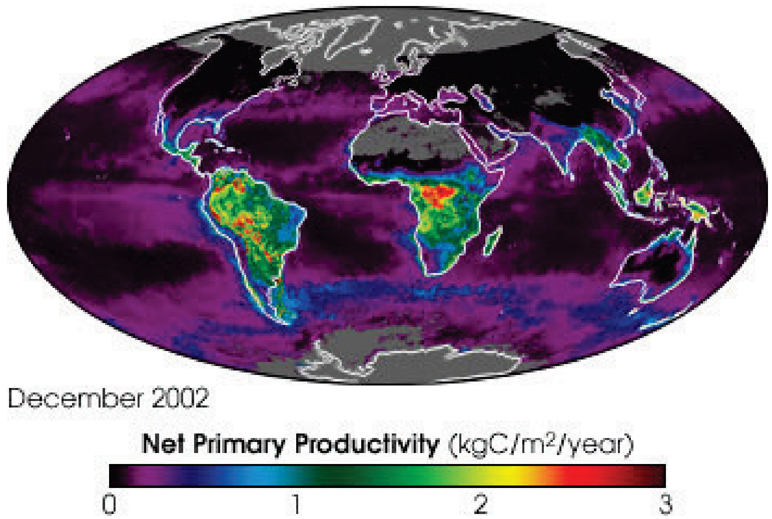

Global net primary productivity (NPP) based on space-based measurements obtained by the NASA MODIS satellite instrument.

Geological Evolution of Earth's Atmosphere:
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  $6\ CO_2 + 6\ H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6\ O_2$ is ~ 57×10^{15} g C yr^{-1}
  Production of atmospheric O_2 is therefore ~152×10^{15} g O_2 yr^{-1}

Note: $152 = 57 \times (32) / (12)$

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

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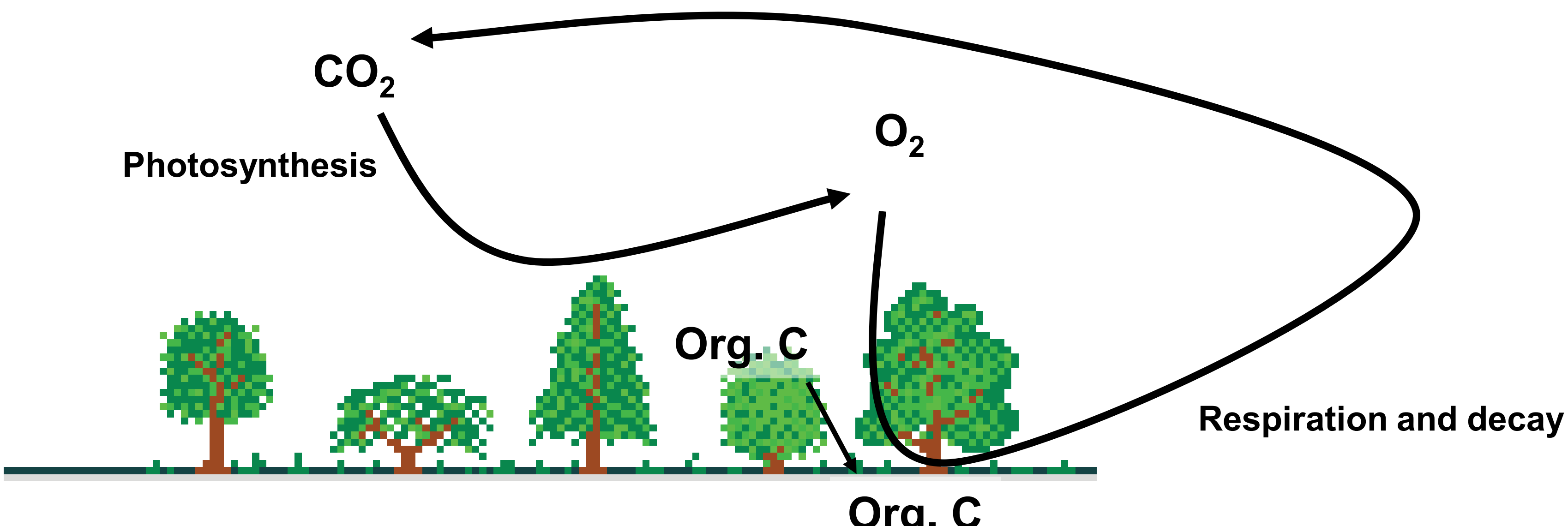
- **Mass O_2 in atmosphere = $0.21 \times (5.2 \times 10^{21}$ g$) \times (32 / 28.8) \approx 1.2 \times 10^{21}$ g**



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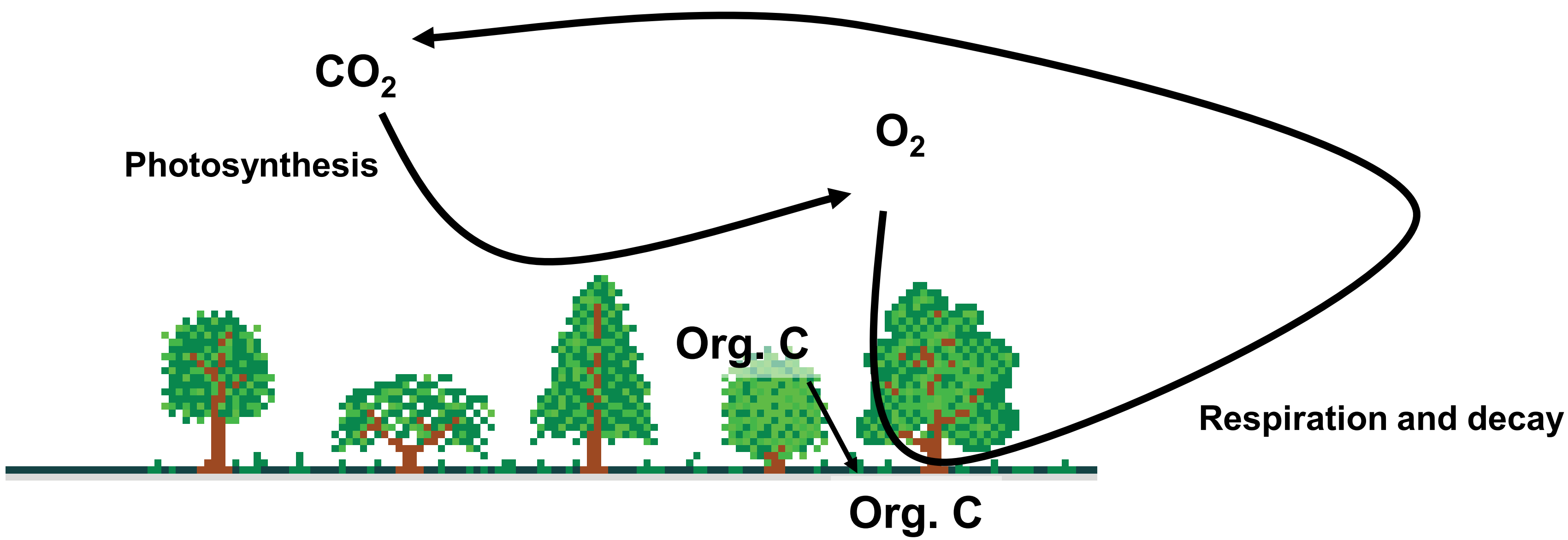
- **Lifetime of atmospheric O_2 due to biology = Amount / Flux**



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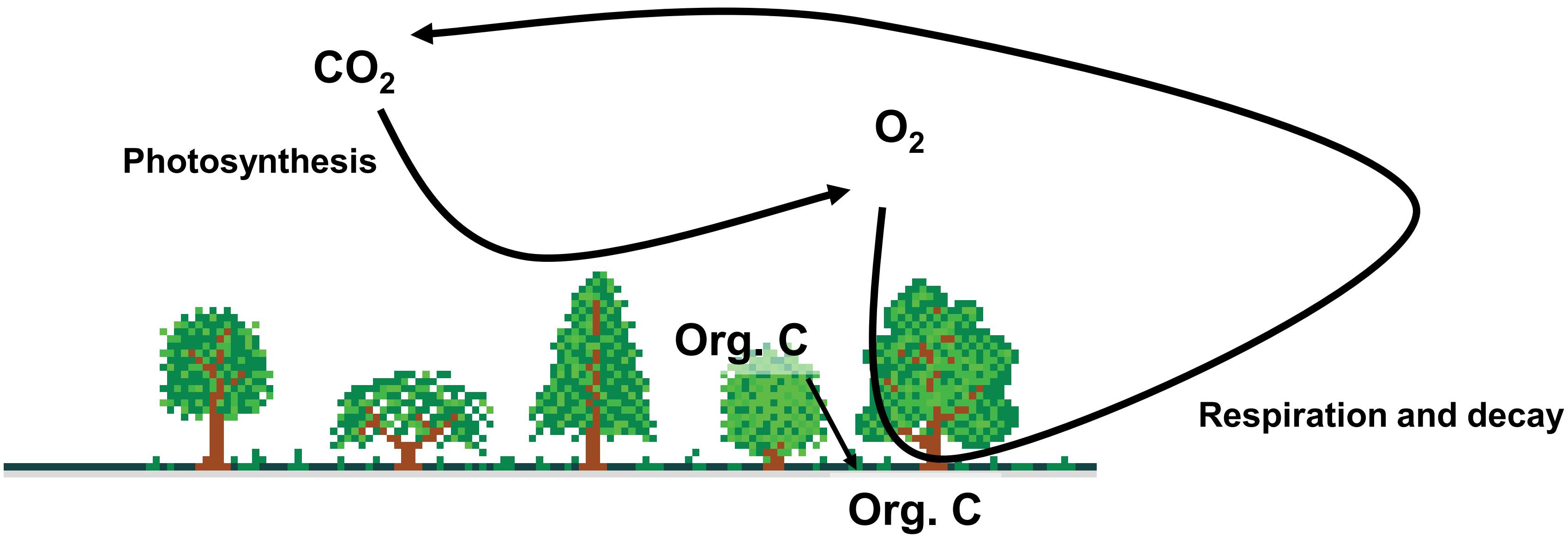

Geological Evolution of Earth's Atmosphere: *Early Atmosphere: Photosynthesis*

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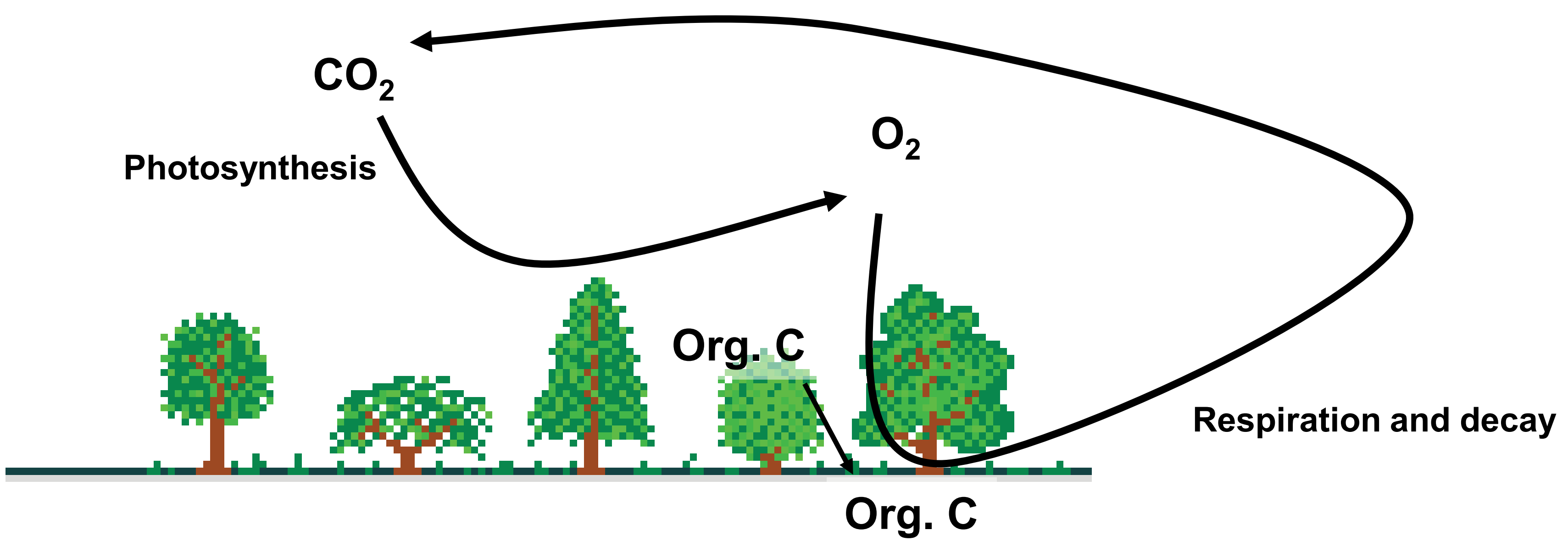
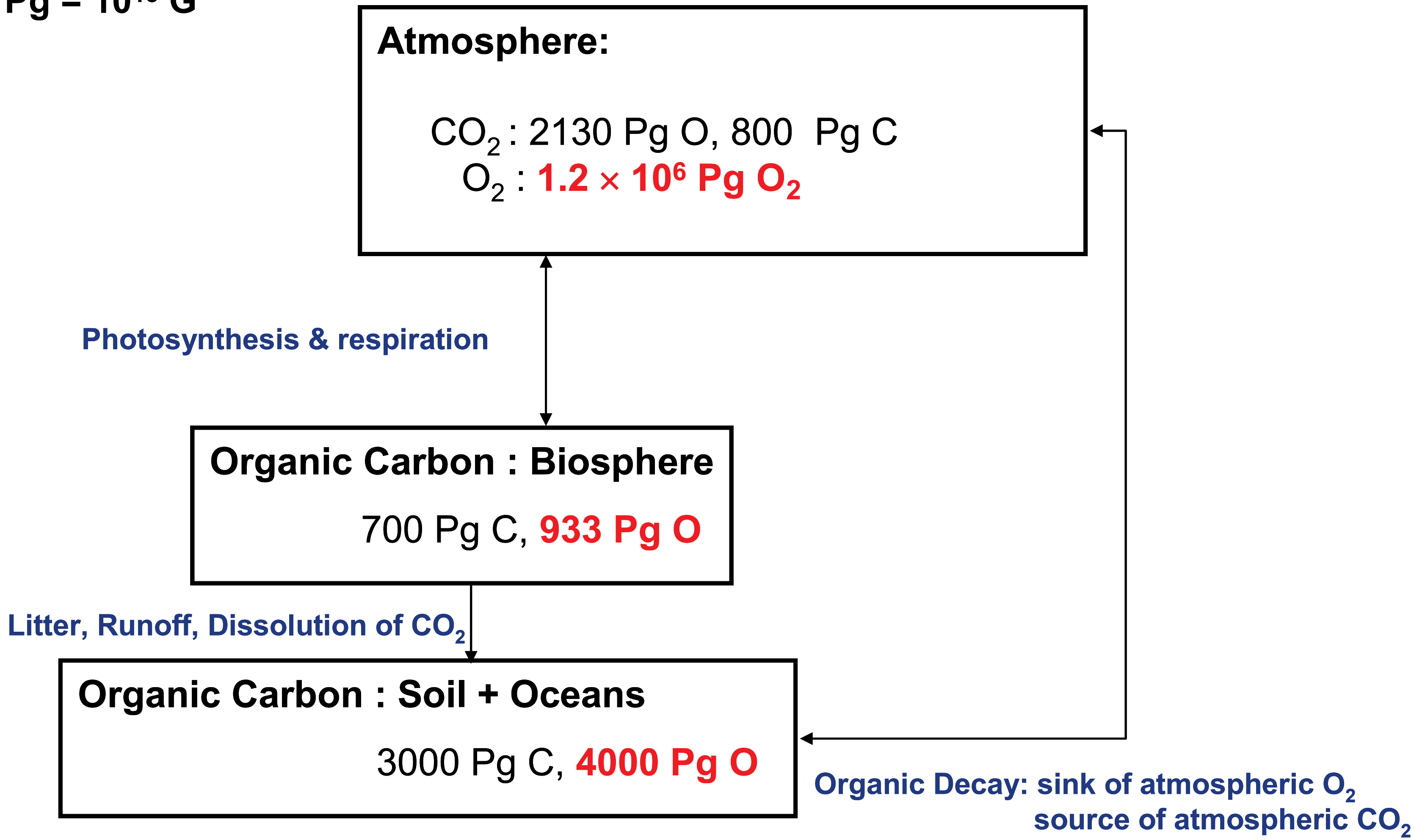
- **Mass O_2 in atmosphere = $0.21 \times (5.2 \times 10^{21}$ g$) \times (32 / 28.8) \approx 1.2 \times 10^{21}$ g** Amount

- **Lifetime of atmospheric O_2 due to biology = 1.2×10^{21} g / (152×10^{15} g O_2 yr^{-1})**
  $\approx$ 8,000 yr



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:

$$6CO_2 + 6\,H_2O + \text{Energy} \rightarrow C_6H_{12}O_6\ (\text{buried}) + 6O_2\ (\text{atmosphere})$$

Sediments: Buried Organic Carbon

O_2 : ~32×10^6 Pg O

O_2 Lifetime ≈ 4 million years

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*

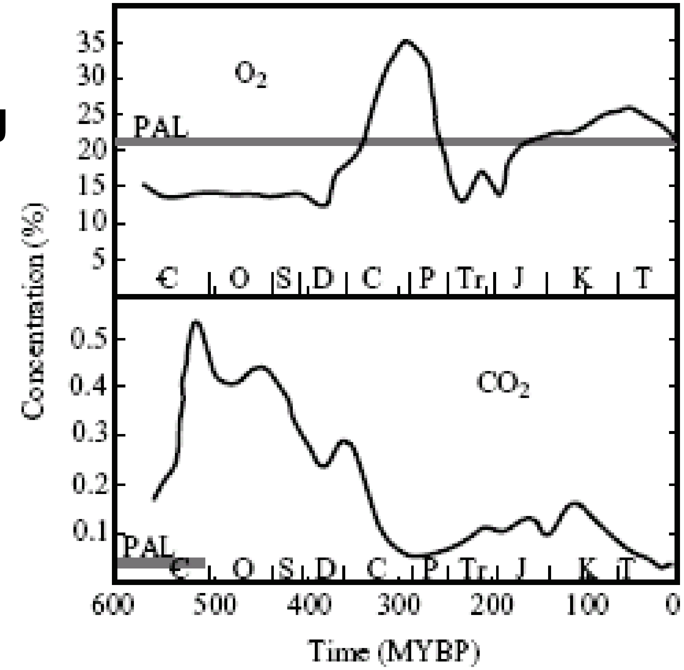
- **Rise of atmospheric O_2 linked to evolution of life:**
  - **400 My B.P. O_2 high enough to form an ozone layer**
  - **400 to 300 My B.P.: first air breathing lung fish & primitive amphibians**

- **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 : δ^{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**

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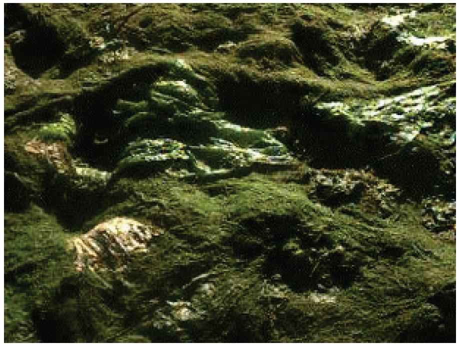
Non-vascular: Bryophytes (moss) **Vascular: Pteridophytes**



The first land plants were algae, which made a difficult transition from their water origins to root on rocky surfaces. The green algae pictured here on top of coastal mudflats would have been a common view of Earth's first land plants.

http://www.ecology.com/feature-stories/quiet-evolution-of-trees/index.html

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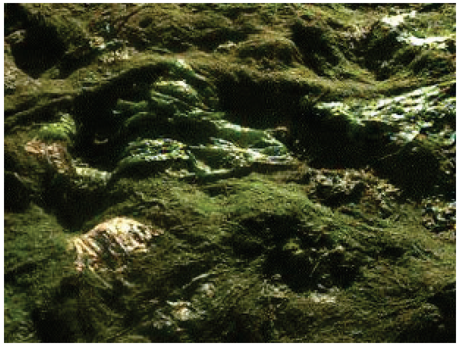
- **Past burial rate of vascular plant material may have been much higher than present, due to the lack (way back when) of abundant bacteria, fungi, and small soil animals that now recycle plant matter**

Non-vascular: Bryophytes (moss)



The first land plants were algae, which made a difficult transition from their water origins to root on rocky surfaces. The green algae pictured here on top of coastal mudflats would have been a common view of Earth's first land plants.

http://www.ecology.com/feature-stories/quiet-evolution-of-trees/index.html

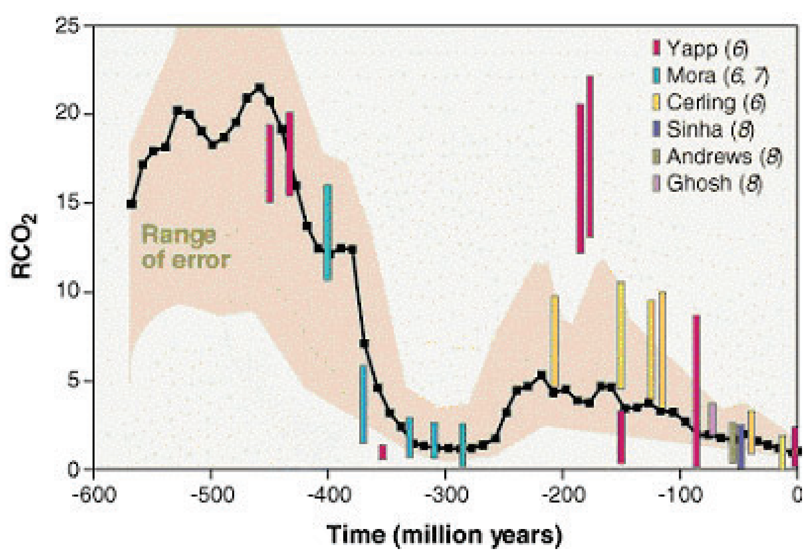
Vascular: Pteridophytes (ferns)

The first trees did not appear until only ~370 million years ago!

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

Outgassing

N_2

CO_2

H_2O

oceans form

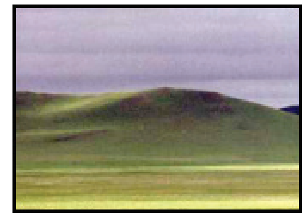
CO_2 dissolves

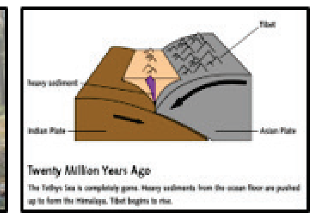
Life forms

Onset of photosynthesis

O_2

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





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

Geological Evolution of Earth's Atmosphere: CO_2 and Temperature

What message were we trying to convey?

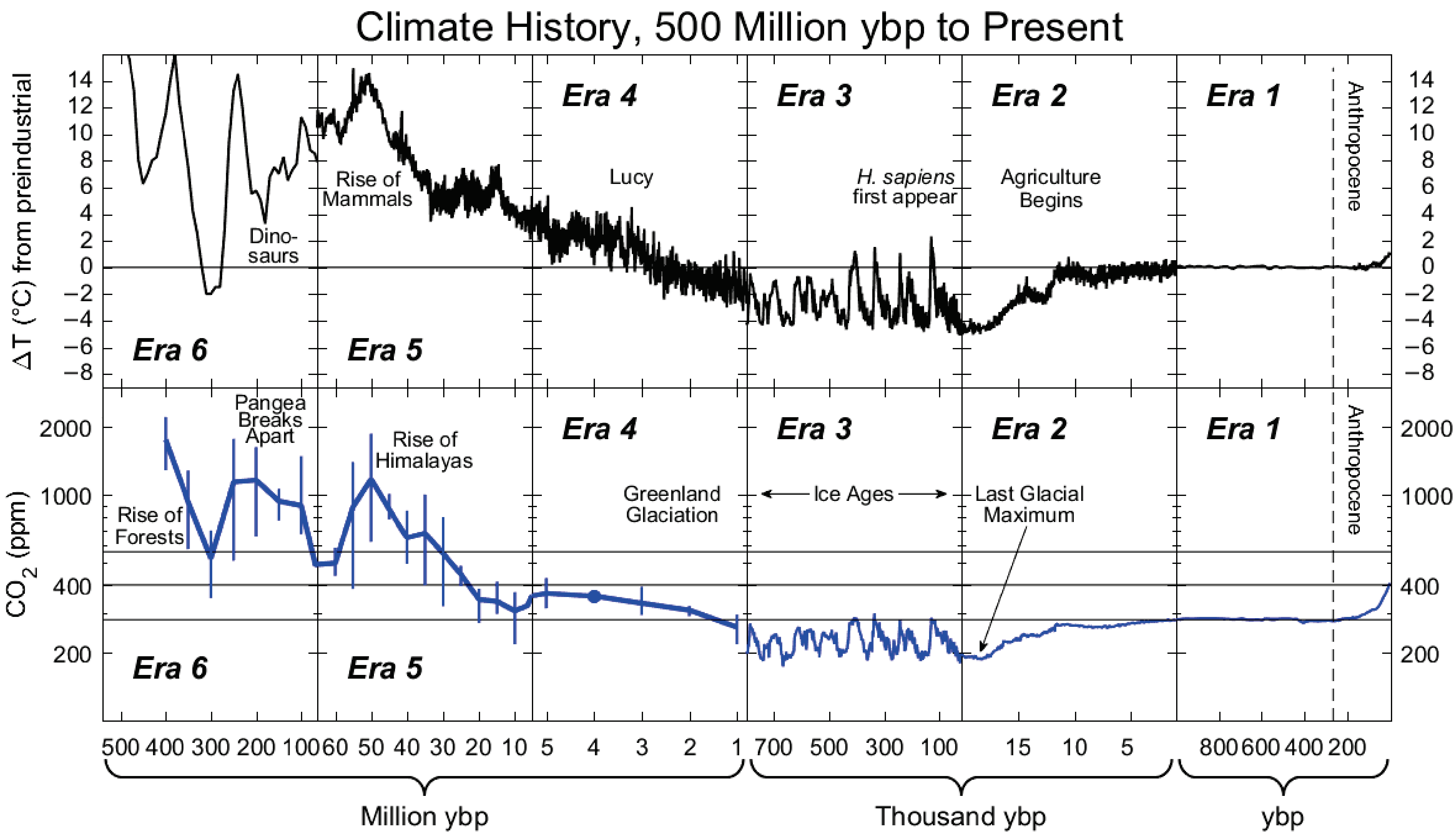
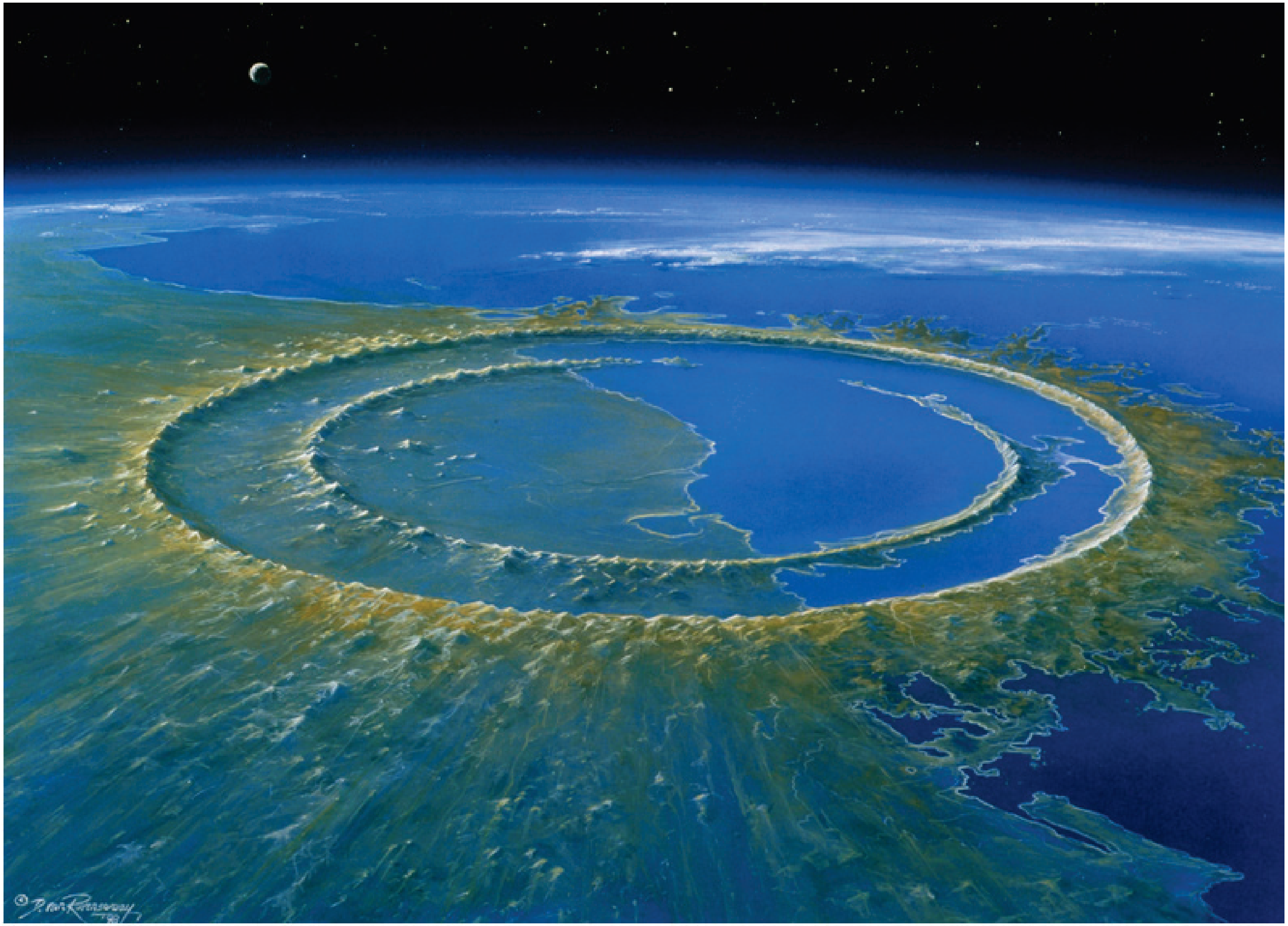


Fig 1.1, *Paris Beacon of Hope*

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

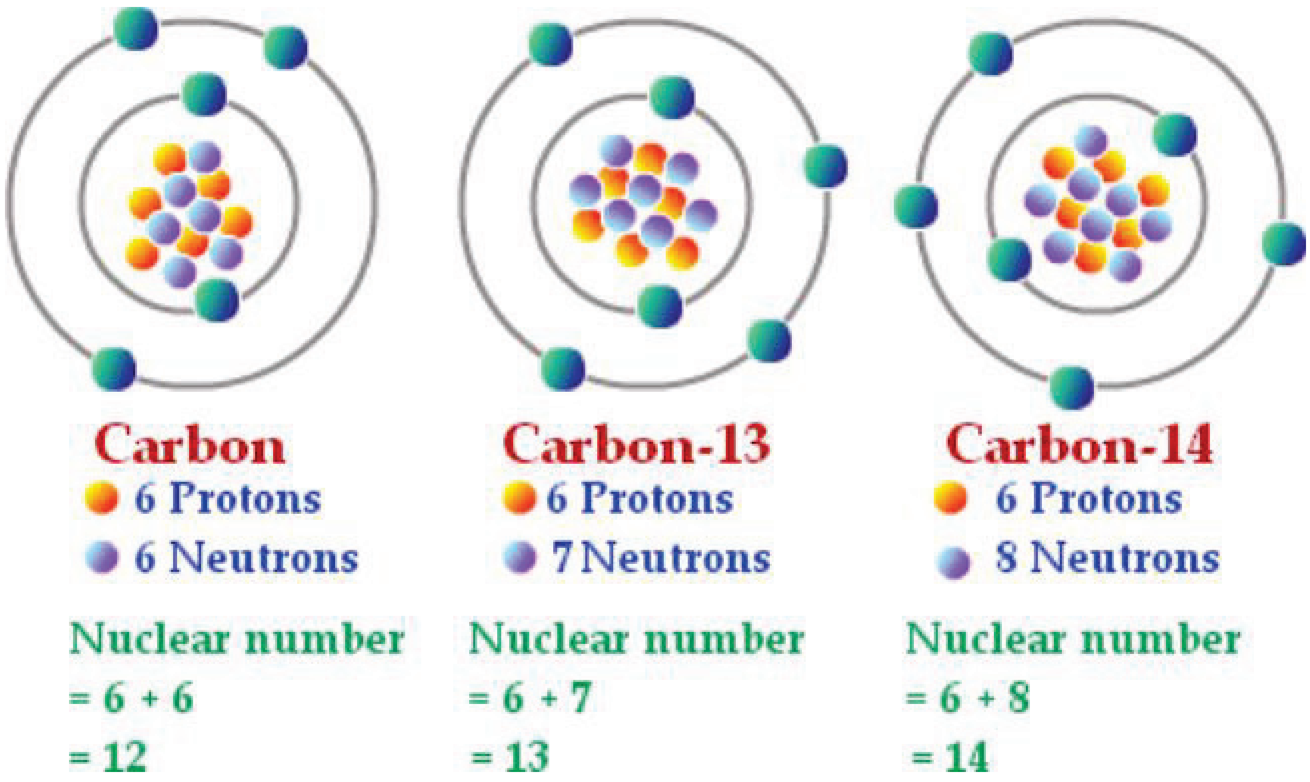
Geological Evolution of Earth's Atmosphere: One Day, ***Everything Changed***

https://www.pbs.org/wgbh/nova/video/day-the-dinosaurs-died

We'll look at 36:50 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.

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

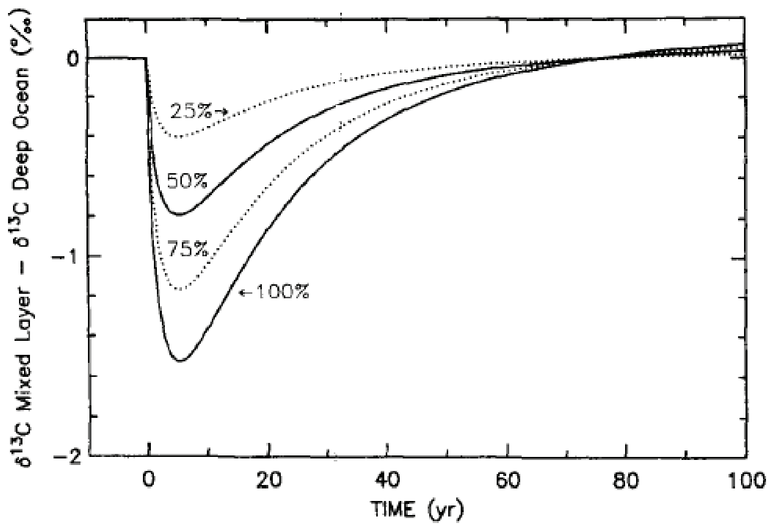


Figure 2. Variation of surface-water to deep-water gradient of $\delta^{13}C$ vs. time for simulations of biomass combustion, assumed to occur instantaneously at time zero. Results are shown for burning 25%, 50%, 75%, and 100% of above-ground biomass (10^{18} g C; $\delta^{13}C = -25.7‰$) at end of Cretaceous 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).

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

N_2

CO_2

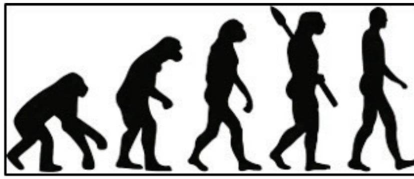
H_2O

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?

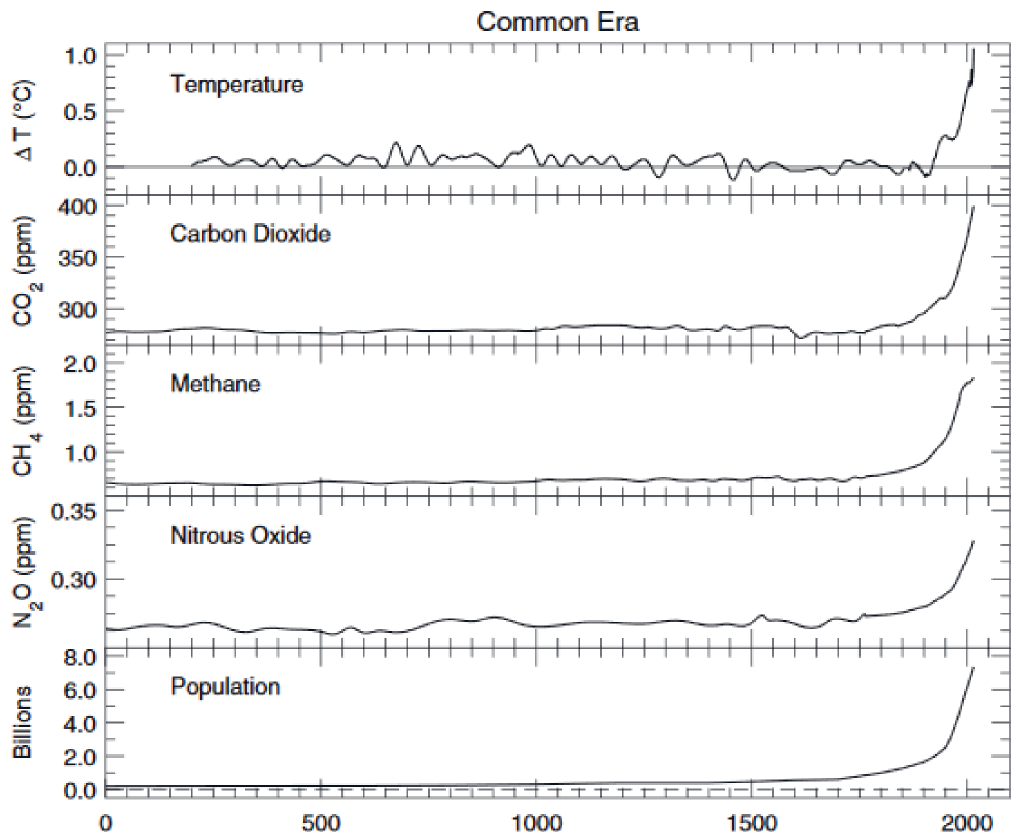
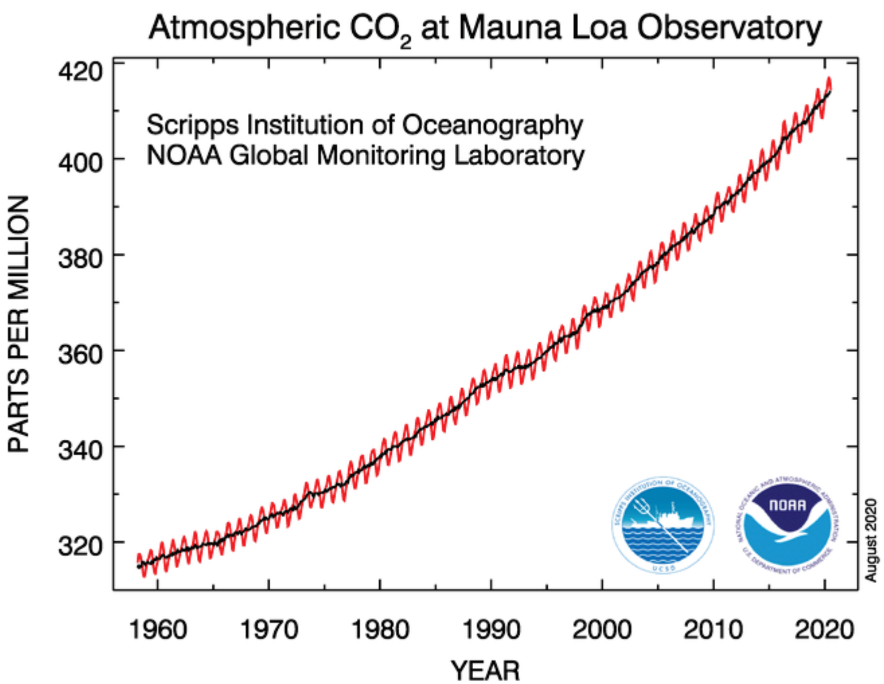


Fig. 1.2 Temperature, GHGs, and population, Common Era. Time series of Earth's global mean surface temperature anomaly (ΔT) relative to pre-industrial baseline (1850–1900 mean) (Jones and Mann 2004; Jones et al. 2012), the atmospheric mixing ratio of CO_2, CH_4, and N_2O (MacFarling Meure et al. 2006; Ballantyne et al. 2012; Dlugokencky et al. 2009; Montzka et al. 2011) and global population (Klein Goldewijk et al. 2010; United Nations 2015) over the Common Era. See Methods for further information

Earth's Atmosphere – Effect of Humans

CO_2: ~412 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

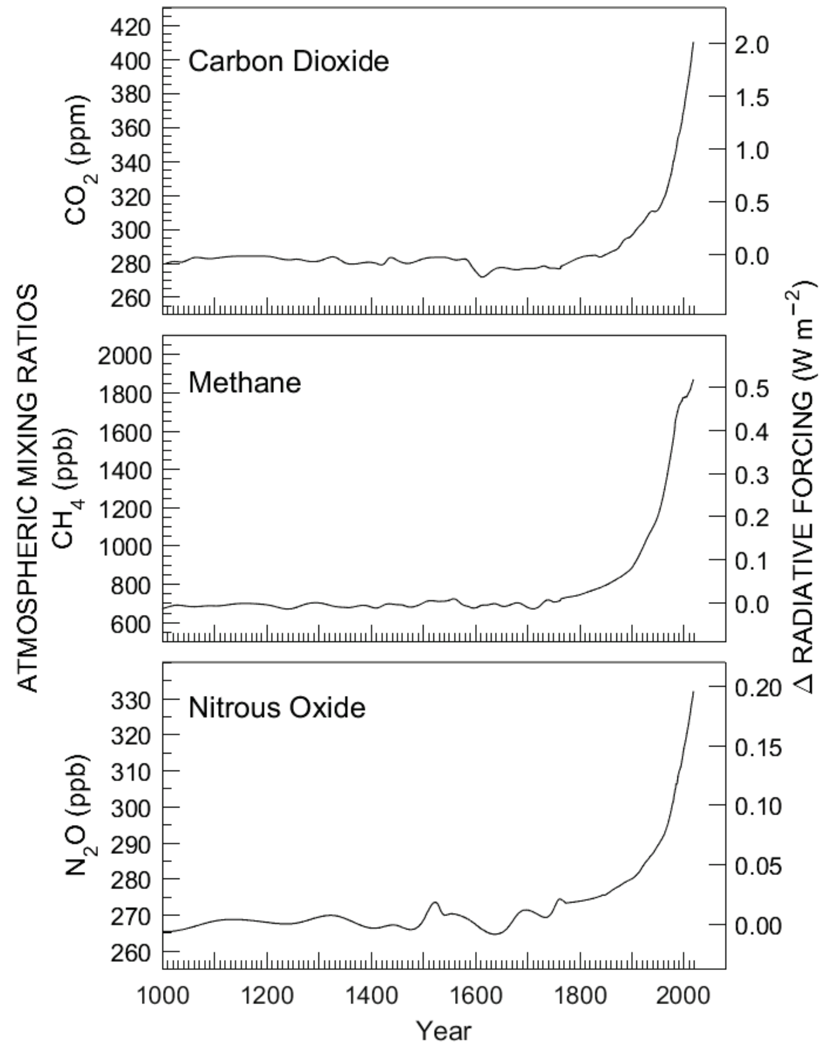
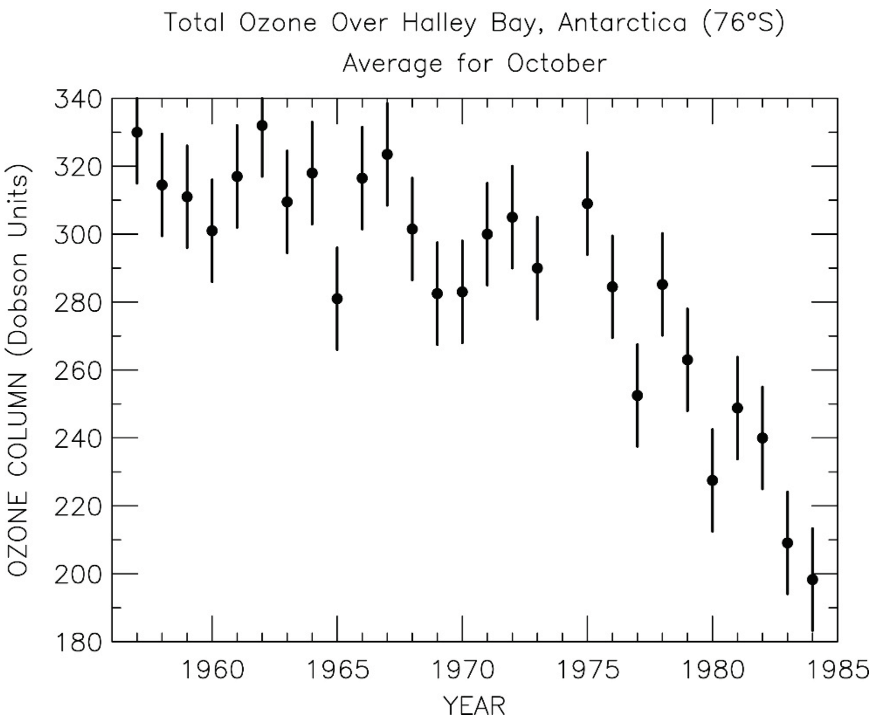


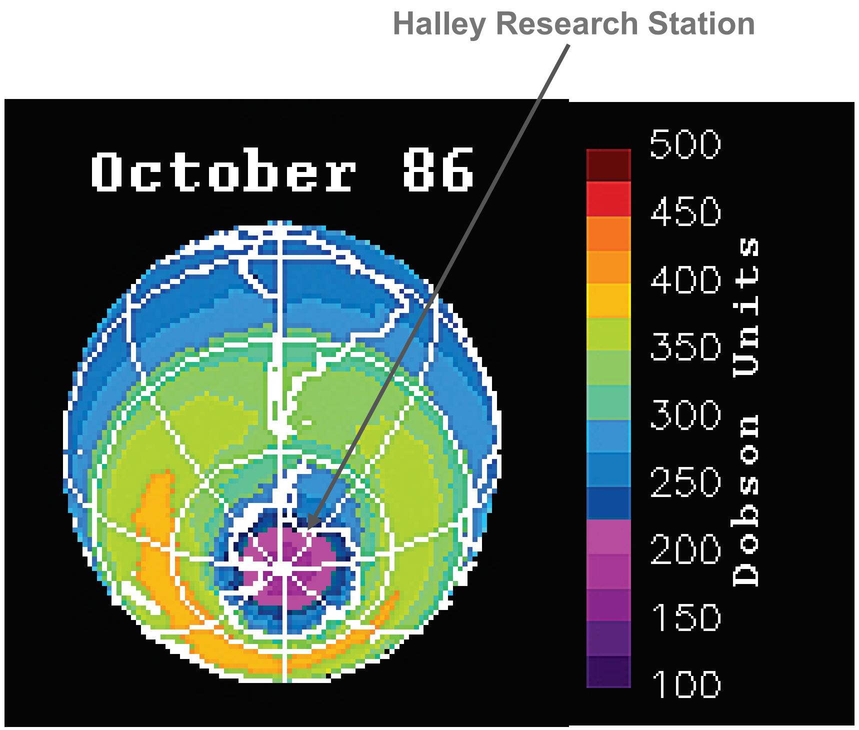
Figure courtesy Brian Bennett, Univ of Md

Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation



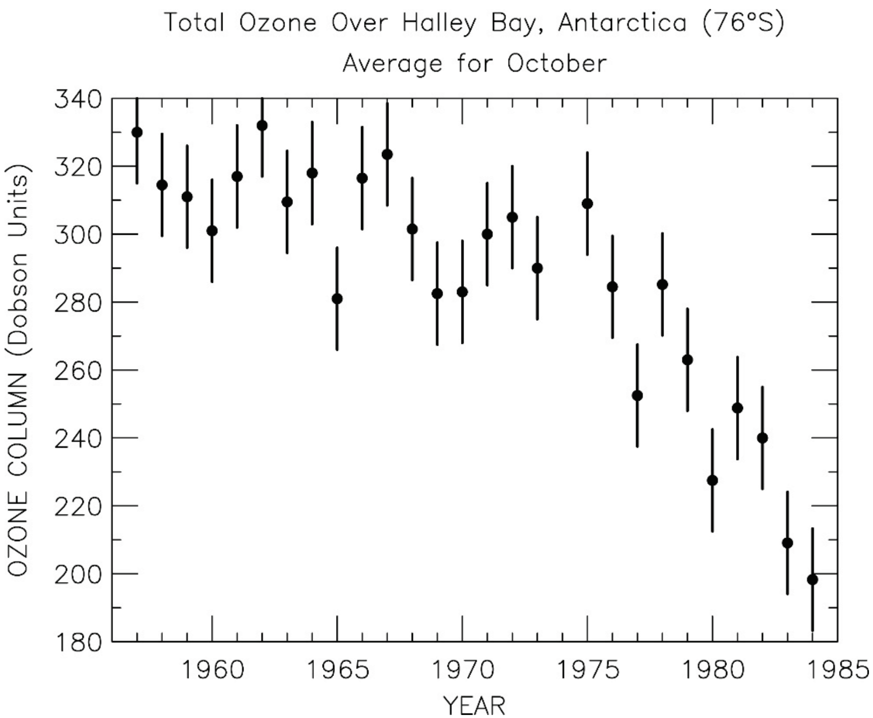
After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.



Stolarski *et al*., Nature, 1986.

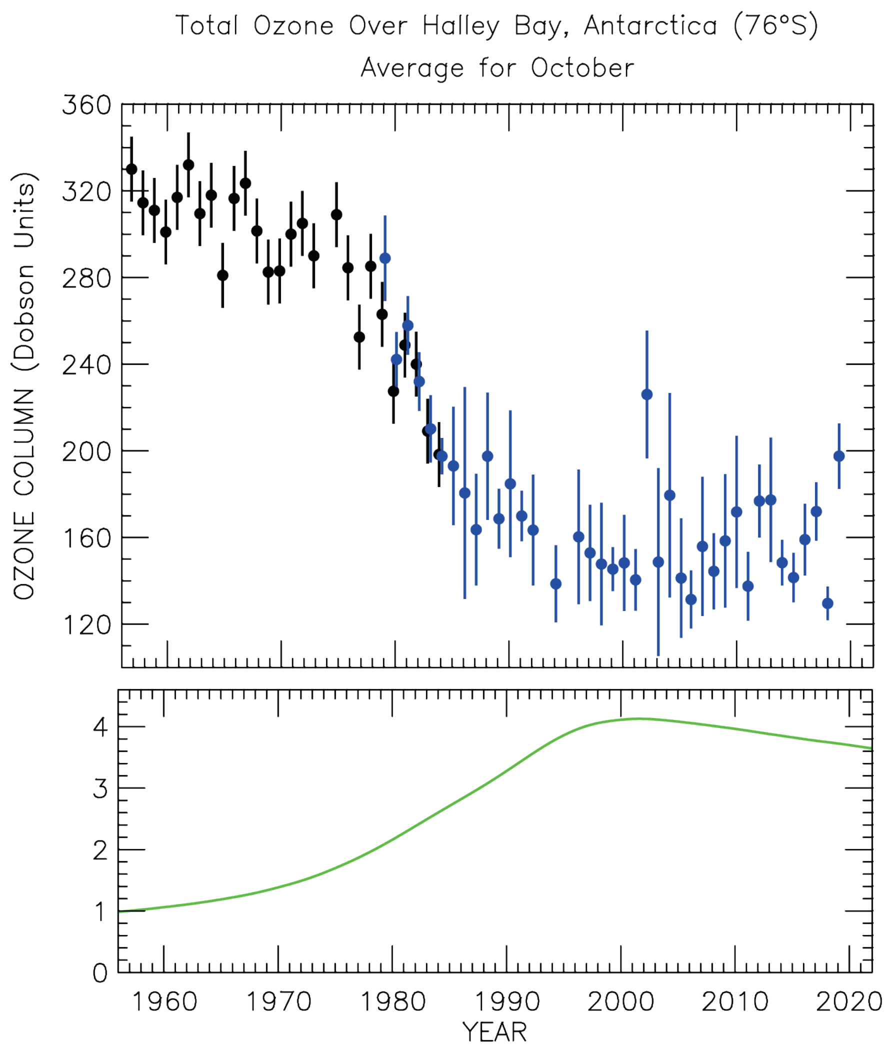
Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation



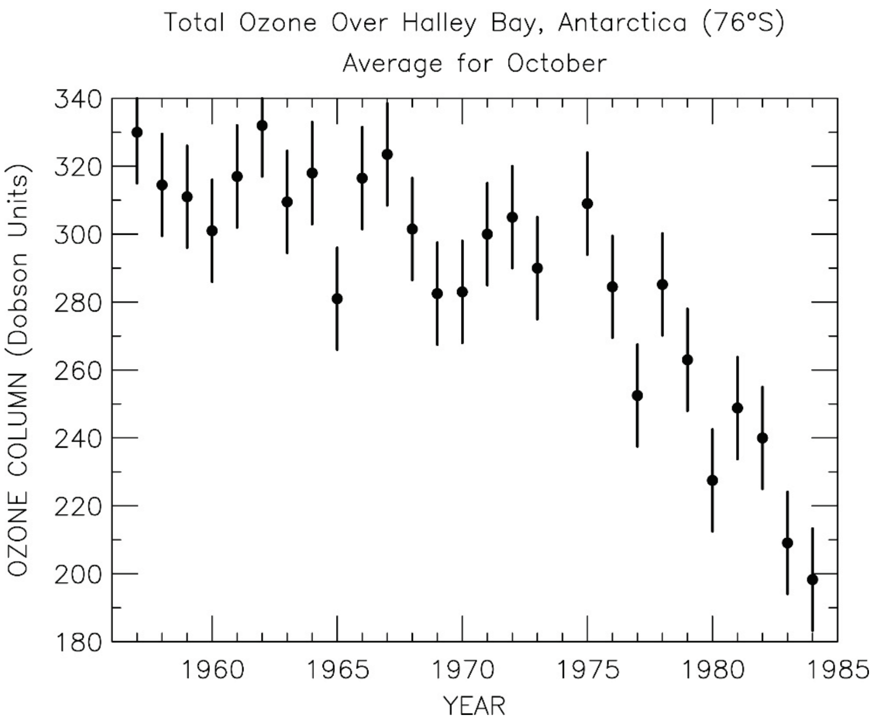
After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.

Update



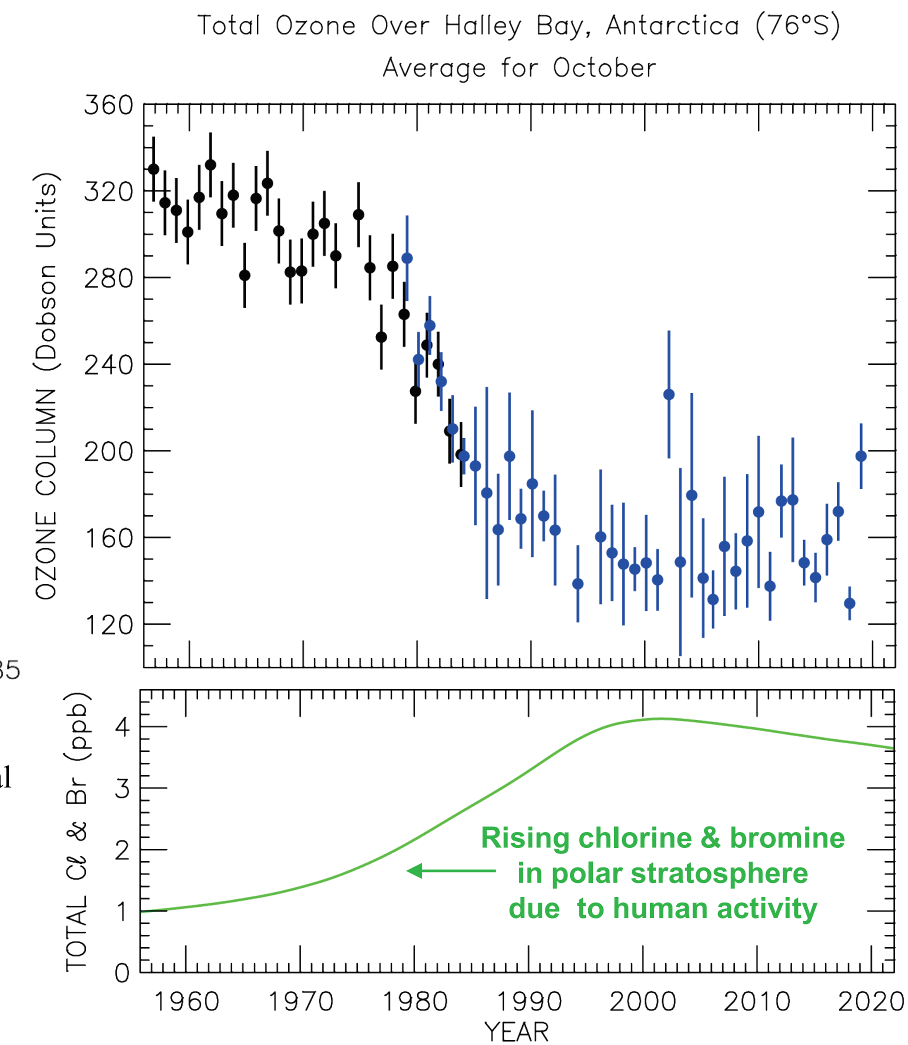
Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation

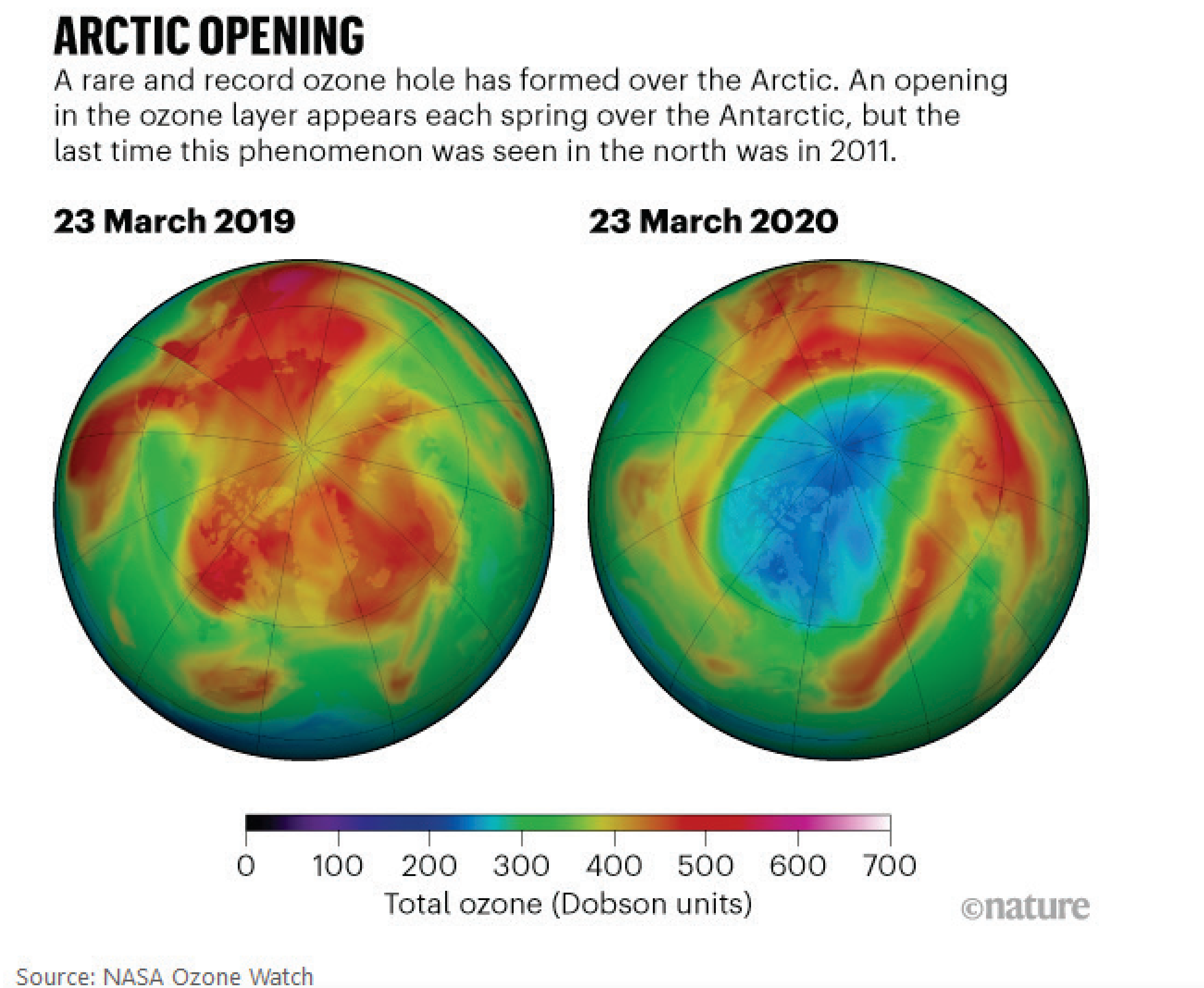


After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.

Update



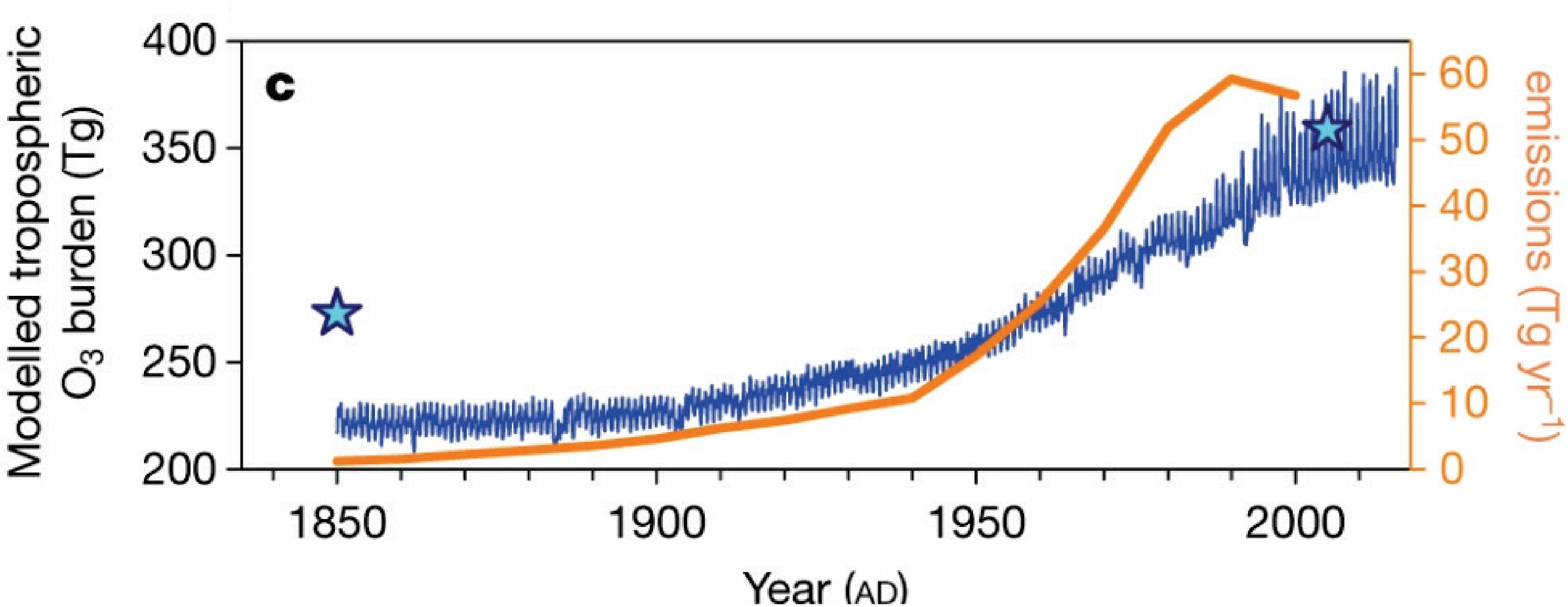
Stratospheric Ozone In The News



https://www.nature.com/articles/d41586-020-00904-w

Earth's Atmosphere – Effect of Humans

Tropospheric Ozone – oxidant, lung irritant, harmful to crops



Modelled increase in tropospheric O_3 burden from the GEOS-Chem/MERRA2 model (cyan stars) and GISS-E2.1 model (blue line), as well as estimates of historical emissions of NO_x (orange line).

Yueng *et al.*, *Nature*, 2019

https://www.nature.com/articles/s41586-019-1277-1

Next Lecture: Course Overview

Readings: IPCC 2007 FAQ 1.1, 1.2, 1.3, 2.1, & 3.1 (11 pages)
EPA Air Quality Guide (11 pages)
20 QAs Ozone Layer Q1, 2, 7, and 14 (11 pages)
Paris Beacon of Hope, Sect 1.2.2 (3 pages)

Note: 36 pages, about our norm

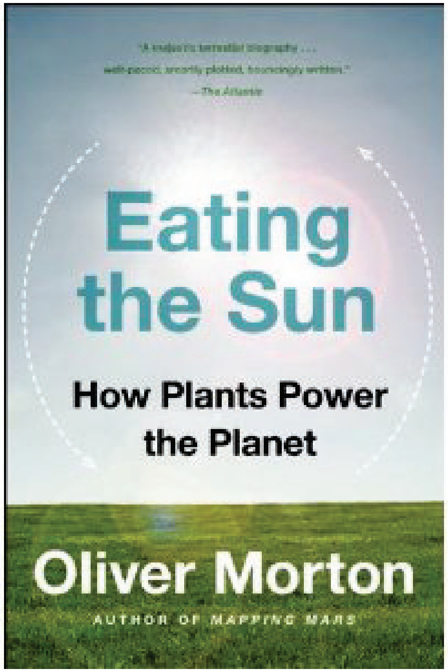
Admission Ticket for Lecture 2 is posted on ELMS

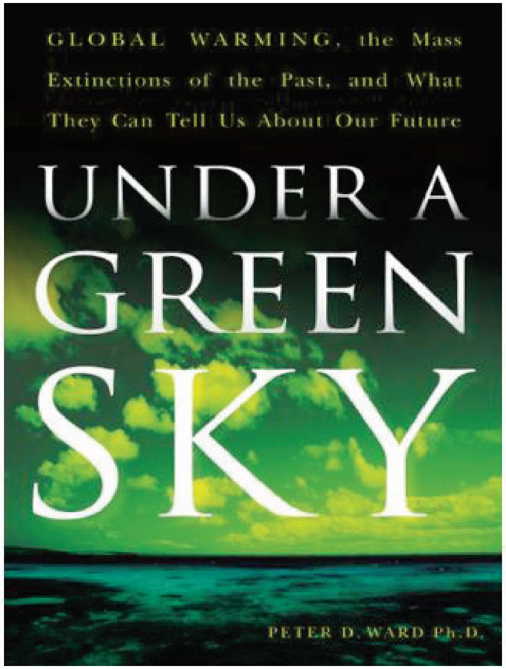
Ross is a newly elected member of the UMD Senate and the first Senate meeting of the semester is Tues, 8 Sept, at 3:15 pm.

As a result, next Tuesday, we will *begin lecture* promptly at 2:00 pm and we will *end lecture* at 3:14 pm

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