How did Earth's atmosphere end up so different?

1. Why did Earth retain most of its water?
2. Why does Earth have so little atmospheric carbon dioxide?
3. Why does Earth's atmosphere consist mostly of nitrogen and oxygen?
4. Where is the ozone coming from?

Why did Earth retain most of its water?

- Earth's atmosphere (due to size) and distance from the Sun allowed the temperature to be right for liquid oceans to form
Why does Earth have so little atmospheric carbon dioxide?

- \( \text{CO}_2 \) is extremely soluble in liquid water
- Oceans (and rain) dissolve gaseous \( \text{CO}_2 \), enabling carbon to be trapped in carbonate rocks (e.g. limestone)

What were the main products of outgassing?

- \( \text{H}_2\text{O} \)
  - Stays in liquid form
- \( \text{CO}_2 \)
  - Trapped by \( \text{H}_2\text{O} \)
- \( \text{N}_2 \)
  - Main component left
- \( \text{SO}_2 \)
  - Trapped by \( \text{H}_2\text{O} \)

Why does Earth's atmosphere consist mostly of nitrogen and oxygen?

- Most of Earth's \( \text{CO}_2 \) (and \( \text{SO}_2 \)) is in rocks and \( \text{H}_2\text{O} \) is in oceans
  - This leaves only nitrogen from outgassing
- Oxygen is harder to create and keep around
  - Not a main product of outgassing
  - Extremely reactive
  - Life is the only explanation!

Where is UV-absorbing ozone (\( \text{O}_3 \)) coming from?

Chemical reactions in the upper atmosphere
Transform some \( \text{O}_2 \) into \( \text{O}_3 \)

The \( \text{O}_3 \) molecules are very effective at absorbing UV light.
Clicker Question

If the Earth were to warm up a few degrees, weather changes would cause more precipitation (e.g. rain). What would this lead to?

A. CO₂ would dissolve more rapidly, the atmospheric CO₂ content would decrease, causing the greenhouse effect to weaken slowly over time.
B. CO₂ would dissolve more slowly, the atmospheric CO₂ content would increase, causing the greenhouse effect to strengthen slowly over time.
C. CO₂ would dissolve more rapidly, the atmospheric CO₂ content would decrease, causing the greenhouse effect to strengthen slowly over time.
D. There would be a runaway greenhouse effect, with Earth becoming ever hotter until the oceans evaporated (as may have happened on Venus).
E. The ice caps would melt and cool Earth back to its normal temperature.

Clicker Question

Why does Earth’s climate stay relatively stable?

Earth’s Built-in Thermostat

- Cooling reduces rain
  - allows CO₂ to build up in atmosphere
- Heating increases rain
  - reduces CO₂ in atmosphere
“Snowball Earth”

- Millions of years ago, Earth apparently got a bit colder than average, and the oceans started to freeze... (Glaciers at equator!)
  - How did this affect the reflectivity?
  - How did the reflectivity affect the temperature?
  - Why aren’t we still frozen today?

'Snowball Earth'

- An example of NEGATIVE FEEDBACK: a change in one direction leads to a change in the opposite direction that returns conditions to “normal”

 CO₂ Cycle & Feedback Keeps Earth Habitable

- The CO₂ cycle causes negative feedback for small temperature changes, giving Earth a stable climate

- May have kept Earth habitable as Sun grew hotter since it formed

  • Takes ~100,000 years to stabilize

Why is Earth Habitable?

- Geology: plate tectonics/volcanism
- Water: abundant and liquid
- Atmosphere: oxygen, stratosphere, little CO₂
- Stable climate (unlike Mars & Venus)
- Life: astonishing and planet-altering

These unique physical properties arise from the right combination of size, distance from the Sun, and rotation rate.
Lessons From Our Neighbors
Tinkering with Earth’s habitability
1) Changing greenhouse gases
2) Changing ozone gases

Is global climate change (aka global warming) real?
A. Yes
B. No

Are humans the cause?
A. Yes
B. No

Average global temperature

- The last decade has been the hottest on record
  - Temperature data for ~120 years recorded from actual thermometer measurements

CO₂ Levels also rising

- CO₂ concentrations 30% higher than ever before
  - CO₂ concentrations obtained from ice cores
- Does temperature depend on CO₂ levels?
  - Venus & Mars show importance of CO₂ greenhouse effect
Periods of higher CO₂ levels coincide with times of higher global average temp

Are humans the cause of the warming?

These models predict more human-made warming in the next century… NOT GOOD!

Consequences of CO₂ increase

- Obvious: Greenhouse effect strengthens
- Weather would distribute the temperature changes unevenly
  - Not just warming everywhere (Global Cooling possible)
- Increased evaporation from oceans (and stronger convection currents) would cause more intense storms
- Oceans expand & polar ice would melt, increasing sea levels and flooding coastal regions
- Effect on ecosystems is much harder to predict!
Intergovernmental Panel on Climate Change received 2007 Nobel Peace Prize!

"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

http://www.ipcc.ch/

Climate Change Misinformation

Skeptical Argument

- The climate has changed before
  - Cycles of warm and cold, this is just a cycle

What the Science Says

- Climate reacts to whatever forces it to change at the time; humans are now the dominant forcing factor

Climate Change Misinformation

Skeptical Argument

- The Sun has been gradually getting warmer since its birth
- In the last 35 years, the Sun has actually been measured to be decreasing its output
- Temperature models show long-term solar increase not enough to account for temp increase

What the Science Says

- CO₂ is just a trace gas
  - CO₂ makes up only 0.0387% of Earth's atmosphere
- As it is, that trace gas (along with H₂O) contributes to 31 degrees of change (remember the no greenhouse temp)
  - A little CO₂ goes a long way!
Climate Change Misinformation

Skeptical Argument
- Even scientists don’t agree on the causes and/or effects

What the Science Says
- Science is the process of testing and retesting (remember the scientific method)
- 97% of climate experts agree humans are causing global warming.

Poll Question

Do these data change your opinion about human influence on global climate change?
A. Yes (I didn’t believe it before, now I do)
B. Yes (I believed it before, now I don’t)
C. No (I didn’t believe it before, still don’t)
D. No (I believed it before, still do)

Poll Question

Have you heard about the ozone hole before?
A. Yes
B. No

Tinkering #2: Ozone Depletion
Tinkering #2: Ozone Depletion

- $O_3$ in stratosphere shields surface from Solar UV
- Ozone hole over Antarctica
  - first sign of depletion discovered in the 1970's
  - Chlorine from CFC's discovered to destroy ozone

- Int'l legislation enacted in 1987 (Montreal Protocol) - but healing takes decades
  - 2012 Ozone hole was the second smallest on record in 20 years
  - Full recovery expected by 2065

Take home message:
(Valuable long after this course is done)

Small changes can lead to big (and drastic) outcomes.