Lecture #12

- Earth: Atmosphere and Climate.
  - Earth's atmosphere.
  - Weather and climate.
  - The greenhouse effect.
  - Cosmic influences on the biosphere.
- Reading:
  - Chapters 10.1, 10.2, 10.6

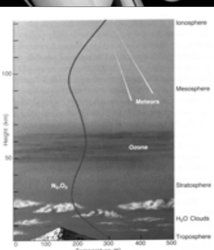
The Main Point

The Earth has a relatively thin but dynamic atmosphere that warms the surface via the greenhouse effect and makes life possible.

Earth's Atmosphere

Composition of the Earth's Atmosphere

Gas	Symbol	Percent	PPM
Permanent			
Nitrogen	N_2	78.08	
Oxygen	O_2	20.95	
Argon	Ar	0.93	
Neon	Ne	0.0018	18
Helium	He	0.0005	5
Hydrogen	H_2	0.00006	0.6
Xenon	Xe	0.000009	0.09
Variable			
Water Vapor	H_20	0 to 4	
Carbon Dioxide	CO_2	.0364	364
Methane	CH_4	.00018	1.8
Nitrous Oxide	N_2O	.000031	0.31
Ozone (Troposphere)	O_3	.000004	0.04
Ozone (Stratosphere)	O_3	.0012	12
Particulates		.000001	0.01

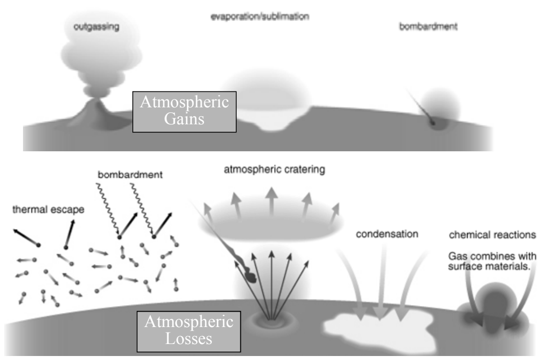


- Highly oxidizing atmosphere ("Non-Equilibrium").
- Surface pressure: 1 bar (~ 1 kg/cm^2).
- 1 bar = 10 m of water.
- Oceans equivalent to 300 bars!

Origin of the Atmosphere

- Three main possibilities:
  - (1) Primordial: Formed along with the rest of the Earth ~4.6 billion years ago. This hypothesis is hard to reconcile with our current understanding of planet formation.
  - (2) Internal: Gases released by volcanic *outgassing* over the history of the Earth. This is likely the main source of atmospheric gases for terrestrial planets.
  - (3) Extraterrestrial: *Volatiles* (materials that evaporate at relatively low temperatures) delivered from impacts of icy comets and hydrated asteroids. Evaporation or sublimation of volatiles is another source of atmospheric gas.

More detail in lecture 18 where we discuss the evolution of Earth's atmosphere.



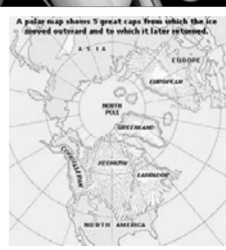
"Weather" vs. "Climate"

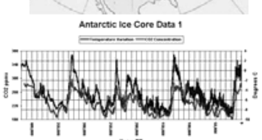
- Day-to-day, quasi-random fluctuations in atmospheric circulation and precipitation are called *weather*.
- Patterns of weather observed over decades to centuries are the *climate.*
- *Weather* changes quickly; *climate* slowly.
- *Climate* changes have occurred throughout Earth's history (how do we know this?)

Evidence for Past Climate Change

- Geologic evidence for massive glaciations: glacially-carved landforms, transported boulders, till, moraines, etc.
- Fossil evidence: periodic fluctuations in warm vs. cold water organisms.
- Variations in Oxygen isotopes: ^{16}O evaporates easier than ^{18}O. When ice caps form, ocean water contains more ^{18}O. Isotopic composition of seashells formed in seawater therefore provides a record of how much ice is present on Earth.
- Greenland and Antarctic ice cores show variations in temperature, dust.
- Last ice age was ~20,000 years ago. Others at 150,000; 250,000; 350,000...

Caused by changes in Earth's orbital parameters?





Will the Climate Change in the Future?

Yes!

Naturally (by fluctuations in Earth's orbital parameters?)

AND

Anthropogenically (i.e. human influences)

The Earth's Surface Temperature

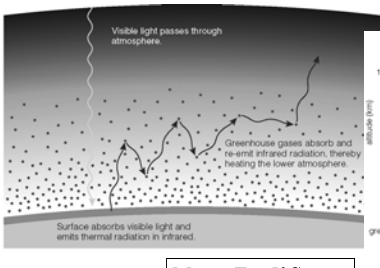
A simple problem with a confusing answer!

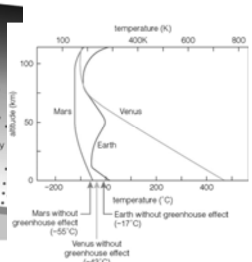
- What is the "equilibrium" temperature of Earth?
  - Amount of incoming energy must balance outgoing energy.
  - Incoming: Sunlight @ 1368 W/m^2 = S_0 (solar constant).
    - Earth "intercepts" an amount = $\pi R_E^2 \bullet S_0$.
    - Some fraction, A, is reflected back into space (A ≈ 0.3).
    - So the fraction (1-A) is absorbed by the ground and heats it up.
    - Therefore the heat input to Earth is $(1\text{-}A) \bullet \pi R_E^2 \bullet S_0$ W/m^2.
  - Outgoing: An object at temperature T emits σT^4 W/m^2.
    - Remember the *Stefan-Boltzmann Law* from Lecture 6.
    - Earth's entire surface emits $4\pi R_E^2 \bullet \sigma T^4$ W/m^2.
  - So to balance, $(1\text{-}A) \bullet \pi R_E^2 \bullet S_0 = 4\pi R_E^2 \bullet \sigma T^4$.
- Solution: T = 255 K = -17°C = 0°F = DAMNED COLD!
- **So WHY AREN'T EARTH'S OCEANS FROZEN?**

The Greenhouse Effect

- Some of the infrared (heat) radiation that would normally escape to space is absorbed by certain gases in the Earth's atmosphere.
- This is the *greenhouse effect*, responsible for warming the Earth by more than 30°C above its equilibrium temperature.
- Carbon dioxide (CO_2) and water vapor (H_2O) are Earth's main *greenhouse gases.*
- Without the greenhouse effect, we would not be here!
- With too much greenhouse effect, we would not be here!

Greenhouse Effect

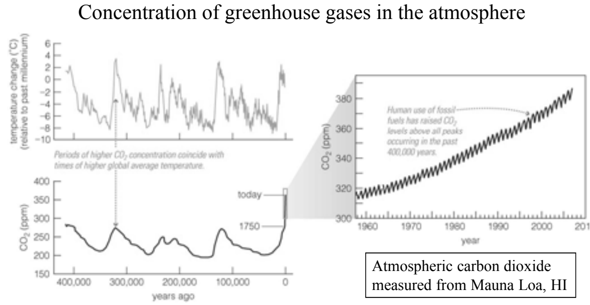




Mars ΔT ~ 5°C
Earth ΔT ~ 35°C
Venus ΔT ~ 500°C!!

An example of human influence

Concentration of greenhouse gases in the atmosphere



Atmospheric carbon dioxide measured from Mauna Loa, HI

Why is CO_2 important?

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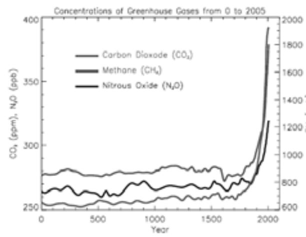
How do we know the change is due to human activity?

This figure is from the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). The panel is a highly respected intergovernmental body composed of governments and hundreds of scientists. The scientific evidence for human-induced climate change is very compelling.

Further warming depends on our emission choices. The most optimistic and most pessimistic IPCC predictions yield carbon dioxide concentrations ranging from two to three times pre-industrial levels by 2100.



FAQ 2.1, Figure 1. *Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)*

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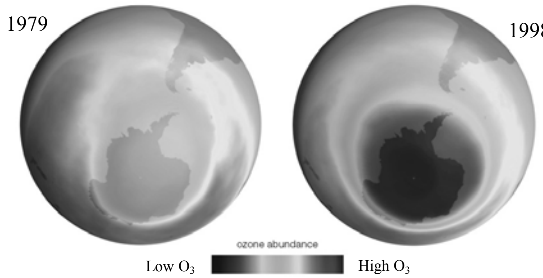
Another example of human influence

The Ozone Hole



Why is Ozone important?

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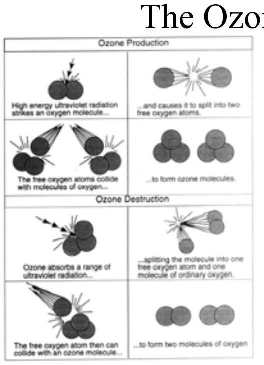
The Ozone Layer



- Creation of ozone blocks high energy UV radiation from getting to Earth's surface.
- Makes life possible!

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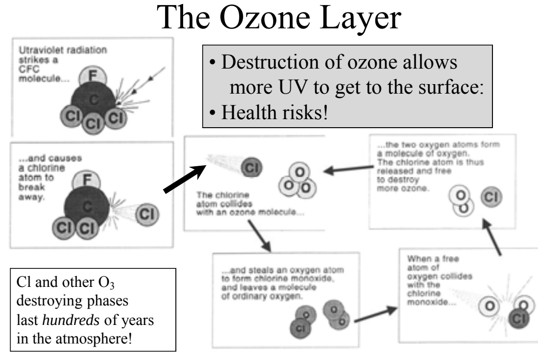
The Ozone Layer

- Destruction of ozone allows more UV to get to the surface:
- Health risks!

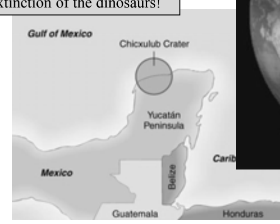


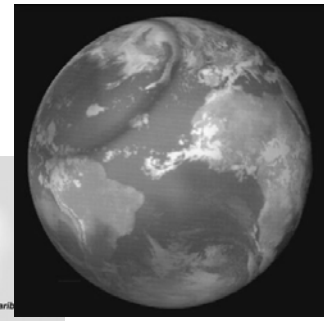
Cl and other O_3 destroying phases last *hundreds* of years in the atmosphere!

Cosmic Influences on the Biosphere

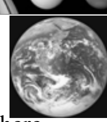
- *Impacts* have occurred on Earth (Lec. 11).
- These catastrophic events appear to have had serious consequences for life on Earth!
  - Severe climate changes: "impact winter".
  - Mass extinctions.
  - Probably influenced the origin of life itself!
- Much more detail in course Parts 3 & 4...

~65 million years ago, a 10-km class asteroid or comet crashed into the Earth, raising a huge cloud of dust that lowered global temperatures for years and probably led to the extinction of the dinosaurs!





Summary



- Earth has a dynamic N_2 & O_2-rich atmosphere.
- Earth's volatiles: primordial or externally-derived?
- Weather vs. Climate.
- CO_2 & H_2O are critical greenhouse gases, warming Earth above the freezing point of water.
- Ozone protects the biosphere against Solar UV.
- Climate changes! (Natural and Anthropogenic).
  - Ice Ages, Global Warming, Impacts.

Next Lecture...

- Surface of the Moon:
  - General Properties of the Moon.
  - Lunar Geology.
- Reading:
  - Chapters 2.3, 9.3, 10.3