Today's goals…

- Composition of the current atmosphere
- How did the atmosphere get this way?

Questions to Think About

- Where did the earth's atmosphere come from?
- Has the Earth's atmosphere always been the same?
- Is there evidence that life has affected the composition of the atmosphere?
- Can we expect the makeup of the atmosphere to change in our lifetimes?

Present Atmospheric Composition

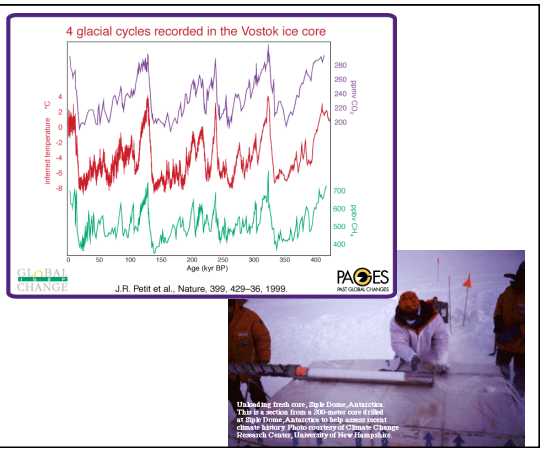
PERMANENT GASES			VARIABLE GASES			
Gas	Symbol	Percent (by Volume) Dry Air	Gas (and Particles)	Symbol	Percent (by Volume)	Parts per Million (ppm)*
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.037	374*
Argon	Ar	0.93	Methane	CH_4	0.00017	1.7
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	0.3
Helium	He	0.0005	Ozone	O_3	0.000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)		0.000001	0.01–0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs)		0.00000002	0.0002

*For CO_2, 374 parts per million means that out of every million air molecules, 374 are CO_2 molecules.
†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

If the numbers do not change with time, what does this mean???

What are the major sources and sinks for:

- Oxygen?
- Water vapor?
- Carbon dioxide?
- Methane
- CFCs
- Ozone
- Nitrogen (trick question)

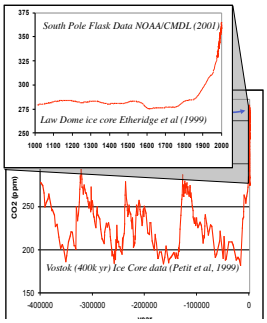


Paleo Carbon Cycling

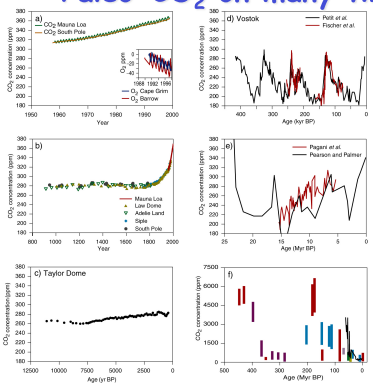
Over the past 420,000 years atmospheric CO_2 has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles.

Over the last millenium, CO_2 was very steady until the Industrial Revolution, when it began to rise rapidly

The atmospheric mixing ratio of CO_2 is expected to reach 700 to 900 ppm by 2100

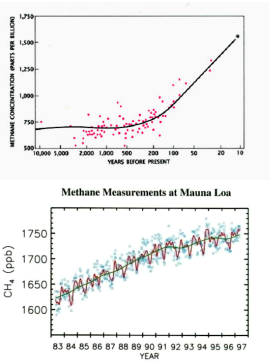


Paleo-CO_2 on many time scales



- Last time CO_2 was this high was > 20 M yrs ago
- 10 to 20x higher hundreds of M yr ago
- Early atmosphere was mostly CO_2!

Atmospheric Methane (CH_4)



- "Reduced" carbon
- A very powerful "greenhouse gas"
- CH_4 has more than doubled since 1800!
- Sources:
  - Natural gas leaks
  - Biomass burning (fires)
  - Anaerobic decomposition (rice paddies, wetlands, cattle guts)
- Sink:
  - Oxidation in atmosphere
- Growth rate has slowed dramatically since 1990, but we don't really know why!

Ozone:

Why is it good for us?

Why is it bad for us?

How is it formed?

How is it destroyed?

Early Atmosphere

- First atmosphere consisted primarily of H and He (most abundant elements in the universe)
- Early Earth was continuously bombarded by high-energy collisions with other bodies
- H & He are very light (MW 1 and 4), easily lost when accelerated past terminal velocity
- Secondary atmosphere was formed primarily through volcanic emissions

Mt. St. Helens

adding to our to

our atmosphere's

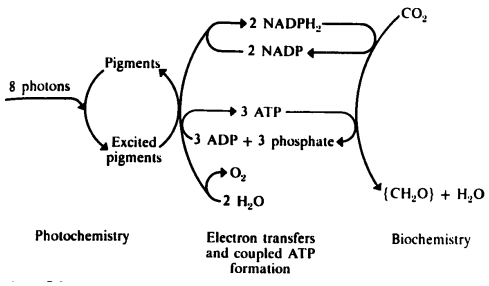
composition in 1980

A more continuous addition of gases and solids to our earth-atmosphere system on the big island of Hawaii

How did the new atmosphere evolve?

1) Volcanic emissions
   - Water vapor 85%
   - Carbon dioxide 10%
   - Nitrogen 1 - 5 %
   - Sulfur 1 - 5 %
   - Particles and surface materials
2) When collisions became less frequent, planet cooled
3) Water vapor condensed, forming oceans
5) Strong acids (HCl, HNO_3, H_2SO_4) dissolved readily into the oceans, taken out of atmosphere, combined with dissolved materials from continental weathering to make sea salt
6) Carbon dioxide dissolved incompletely in the oceans
   $H_2O + CO_2 \rightarrow H^+ + HCO_3^- \rightarrow 2H^+ + CO_3^{2-}$
7) Dissolved carbonate (CO_3^{2-}) in oceans combined with dissolved Ca from continents to form limestone ($CaCO_3$)
8) There's enough carbon in limestone rock today to make 100 atmospheres of pure CO_2!

Photosynthesis



- **Uses solar energy to convert oxidized, inorganic CO_2 to reduced, organic carbon in an oxidizing environment**
- **Stores solar energy at the base of the food chain**
- **Splits water molecules to produce O_2**

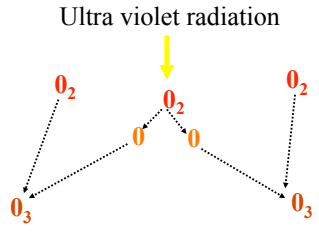
Photosynthesis, Decomposition, and O_2

- Marine photosynthesis evolved at least 2.3 billion years ago (half the age of the Earth)
- Releases free O_2
- When living things die, organic matter is decomposed (oxidized) back to CO_2
- No net change in CO_2 or O_2 if this happens!
- Slow, steady burial of reduced organic material led to steady increase of O_2
- CO_2 was steadily drawn down by both limestone formation and organic burial to trace amounts
- O_2 levels increased dramatically around 2.25 billion years ago, allowed ozone layer and land plants
- N_2 is pretty unreactive … gets left behind. This is why current atmosphere is mostly N_2

Requirements for photosynthesis

- Life forms
  - First bacteria, later plants
- Sunlight
- Shielding from lethal ultraviolet radiation
- Limited by
  - AREAL DISTRIBUTION OF O_2 PRODUCERS
    - INITIALLY DETERMINED BY SHIELDING FROM UV RADIATION
  - EFFICIENCY OF ORGANISMS IN THEIR PRODUCTION OF O_2

Photochemical Production of Ozone



3 O_2 + ultra violet radiation → 2 O_3

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