Chapter One
The Composition and Structure of the Atmosphere

Terms and Definitions

Atmosphere – The mixture of gases, water droplets, and solid particles above the earth's surface
Weather – Short-term atmospheric phenomena lasting from hours up to about a week (e.g. thunderstorms, hurricanes, periods of high winds, drizzle)
Climate – Long-term atmospheric conditions lasting from weeks to years (e.g. average yearly Baghdad precipitation, global warming)
Meteorology – The study of weather
Climatology – The study of climate

Thickness of the Atmosphere

How high is the atmosphere?

- No defined top
- 99.99997% of atmosphere is below 100 km (60 mi)
- Weather occurs in lowest 11 km (7 mi)
- Atmospheric depth is very thin relative to earth's horizontal distances

The Evolution of the Atmosphere

Earth's early atmosphere contained mostly hydrogen and helium

- Two hypotheses exist that explain the dispersion of this early atmosphere
    1. The gases escaped to space by overcoming gravity with large enough escape velocities
    2. Collisions between earth and other large bodies launched the early atmosphere to space
- A modern atmosphere began to form through outgassing by volcanic eruptions, and possibly through collisions of comets with earth (Both supplying mostly carbon dioxide and water vapor)
- Water vapor condensed and precipitated to form oceans

- Carbon dioxide lost to oceans
- Oxygen released first through primitive oceanic bacteria, later through plants (protected by ozone layer)
- Plants further reduced carbon dioxide
- Nitrogen slowly increased over long periods of time through outgassing

Composition of the Modern Atmosphere

The atmosphere today contains:

- Gases (permanent and variable)
- Water droplets (clouds and precipitation)
- Microscopic solid particles (aerosols)

The Permanent Gases

Permanent gases form a constant proportion of the atmosphere, and have long residence times (thousands to millions of years)

TABLE 1-2 Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

The Variable Gases

Variable gases vary in atmospheric concentration in both time and space

TABLE 1-3 Variable Gases of the Atmosphere

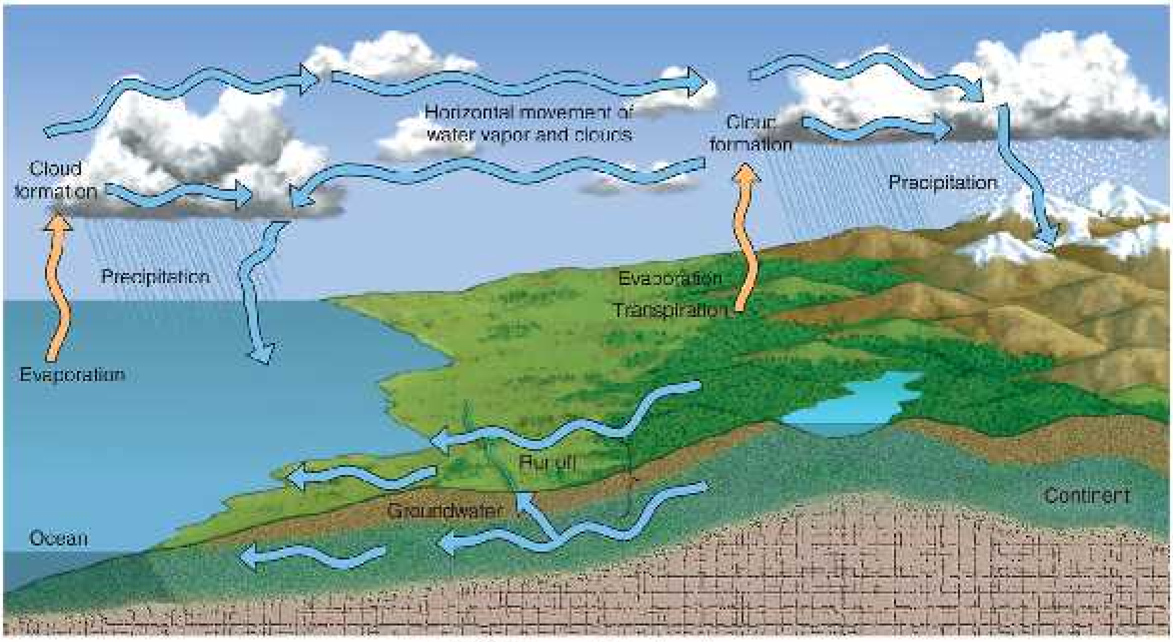
Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H_2O	0.25	18.01
Carbon Dioxide	CO_2	0.038	44.01
Ozone	O_3	0.01	48.00

Water Vapor

Water vapor (H2O) – Extremely important variable gas with short residence time (~10 days)

- Water vapor is the invisible gaseous phase of water (you can only see liquid water droplets!)
- Atmospheric concentration highest near ocean surface in tropics (~4%)
- Atmospheric concentration lowest in deserts and at high altitudes (near 0%)

The Hydrologic Cycle



Water Vapor Satellite Imagery

- Satellite imagery reveals variable nature of water vapor concentration
- Water vapor satellite imagery also reveals moist and dry regions of the atmosphere (visible imagery does not)

Water vapor imagery

(a)

Visible imagery

(b)

Carbon Dioxide

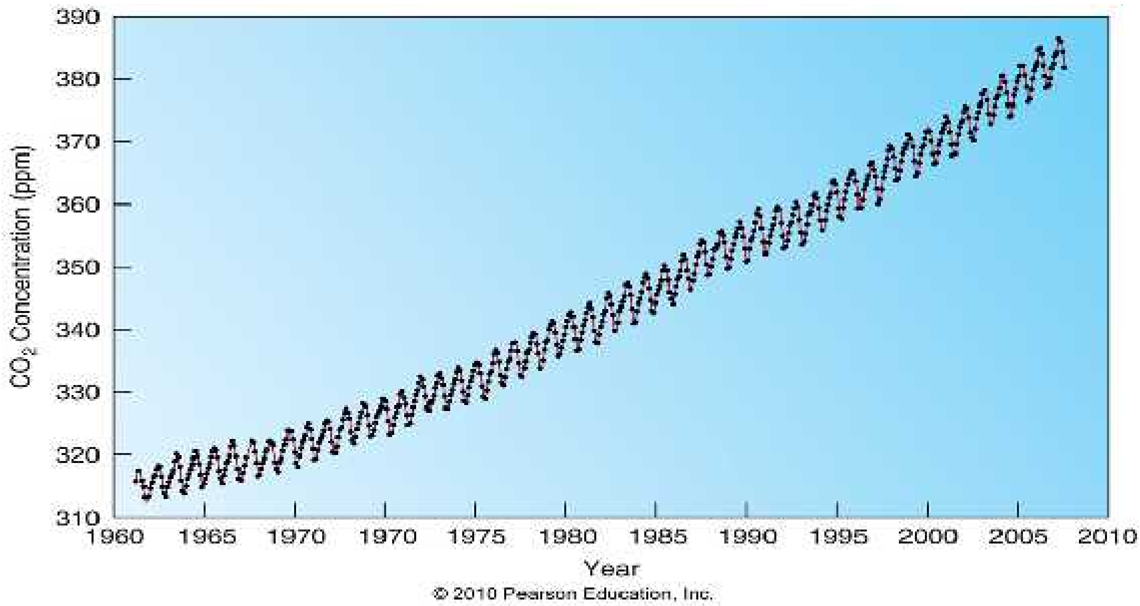
- **Carbon dioxide (CO_2) –** An important greenhouse gas with concentration 0.0386% (386 ppm) and residence time of 150 years

  - Sources - 1) Plant and animal respiration

2) Volcanoes
3) Organic decay
4) Combustion

- Sinks - 1) Photosynthesis (plants)
2) The oceans

- Seasonal oscillation in concentration
- Long term increase in concentration (due to anthropogenic combustion and deforestation)



Mauna Loa Observatory (~11,000 ft. in Hawaii)

Ozone

Ozone (O_3) **–** A beneficial and harmful variable gas

- O_3 concentrations in the stratosphere (~15-50 km above sea level) are relatively high (15 ppm), occurs from natural chemical reactions

→ Absorbs UV radiation!!

- O_3 concentration near earth's surface is usually near zero, but can increase to 0.15 ppm through chemical reactions in polluted air

→ Irritant!!

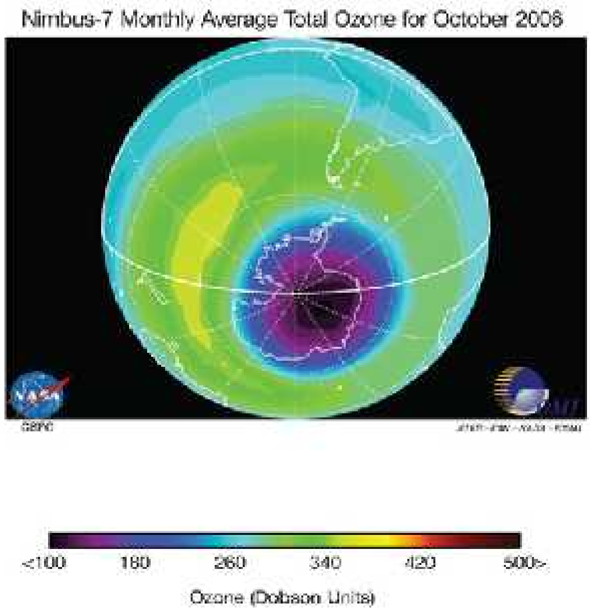
Stratospheric Ozone Creation and Destruction

- Natural ozone cycle

$$O_2 + uv \rightarrow O + O$$
$$O_2 + O \rightarrow O_3$$
$$O_3 + uv \rightarrow O + O_2$$

- After introduction of CFCs

$$CFC + uv \rightarrow Cl + CFC^{byproduct}$$
$$Cl + O_3 \rightarrow ClO + O_2$$
$$O + ClO \rightarrow Cl + O_2$$

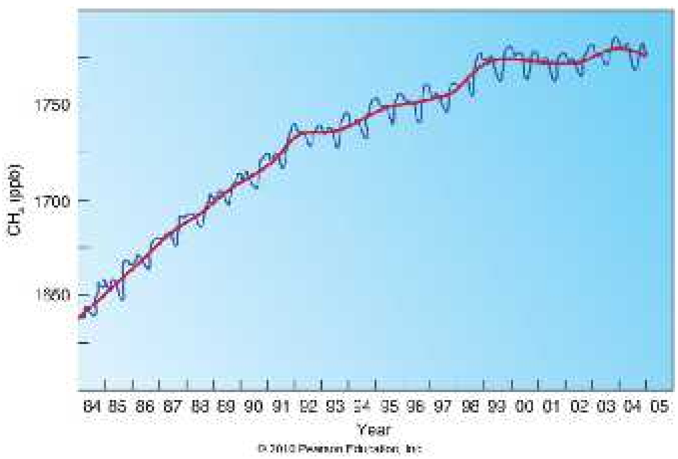


Methane

- **Methane** (CH_4) – A variable gas with residence time ~10 years that has high potential for greenhouse warming

  Sources - 1) Rice cultivation, wetlands
  2) Mining
  3) Biomass burning
  4) Fossil fuel extraction
  5) Animal digestion

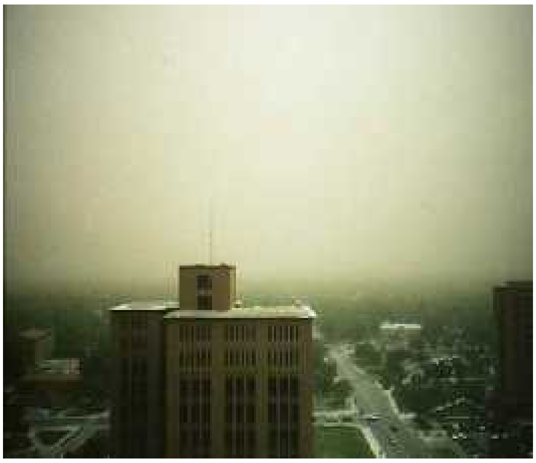
  Sinks - 1) Atmospheric chemical reactions



Aerosols

- **Aerosols –** Small solid particles (e.g. dust, smoke, sea spray, volcanic ash)

  Typical concentration = $1{,}000/cm^3$
  Typical diameter = 10 microns (0.00001 meter)
  Typical life span = days to weeks
  Mostly from natural sources
  Primary sinks include dry and wet deposition
  Act as cloud condensation nuclei (without aerosols, there would never be clouds)

Lubbock, Texas Dust Storm

Forest fire smoke in CA

Haboob in Phoenix, AZ

Eruption of Mount St. Helens

Vertical Structure of the Atmosphere

There are various ways to characterize the vertical nature of the atmosphere

- Density profile
- Temperature profile (Most common)
- Chemical profile
- Electrical profile

The Chemical Profile

Homosphere – The atmosphere below 80km (~50miles)

- Permanent gases are in constant concentration
- Generally, "atmosphere" refers to the homosphere

Heterosphere – Above the homosphere

- Lighter gases dominate (helium, hydrogen)
- No permanent gases

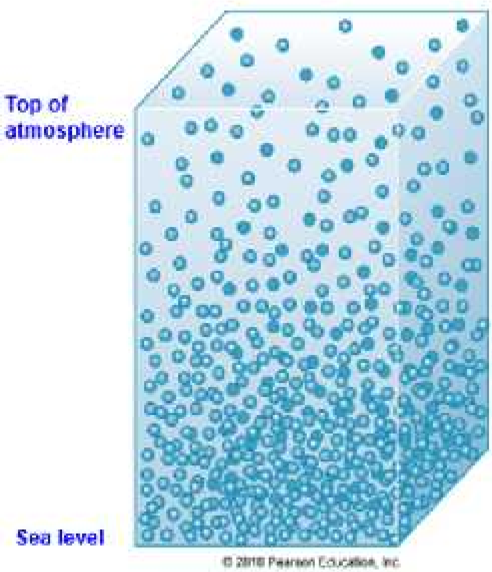
The Density Profile

Density is defined as the amount of mass per unit volume

<u>Density of various materials</u>

Water	1000 kg/m^3
Steel	7800 kg/m^3
Air (at sea level)	1.2 kg/m^3

- The atmosphere is compressible
- Density decreases with height



Atmospheric Pressure

How does pressure decrease with height in the atmosphere?

Pressure decreases with height fastest near the surface, less so aloft

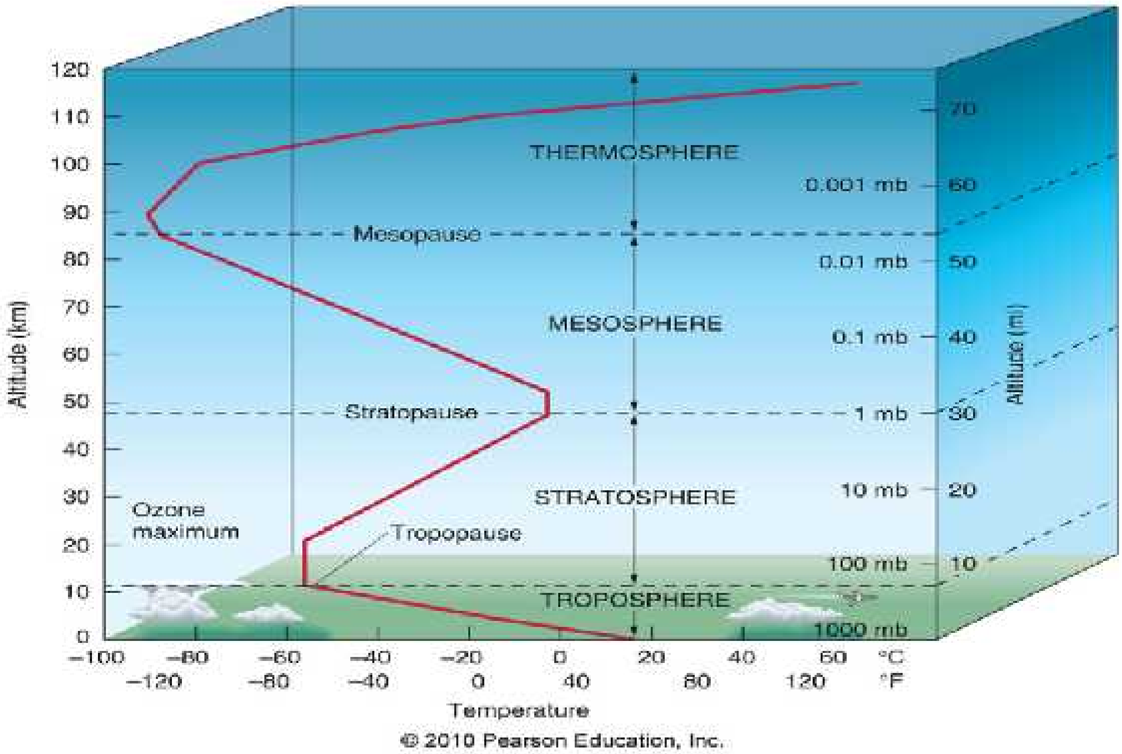
How much pressure (psi) is pushing on you right now?

Average sea-level pressure = 14.7 psi
= 1013.25 mb
= 101325 Pa
= 29.92 in Hg
= 1 atmosphere

Record high sea-level pressure = 1083.8 mb (Siberia, 1968)
Record low sea-level pressure = 870 mb (Typhoon Tip near Guam, 1979)

Layering the Atmosphere Based on Temperature

4 layers identified by similar temperature rates of change with height



A Quick Note on Temperature…

Temperature is expressed in Fahrenheit (^oF), Celsius (^oC), or Kelvin (K)

Conversions

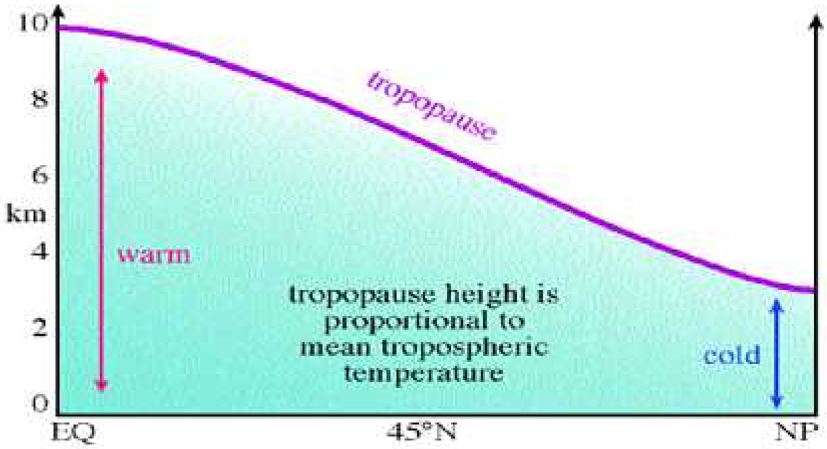
$$K = {}^oC + 273.16$$

$$^oF = (9/5) * {}^oC + 32$$

Troposphere

Troposphere – Lowest atmospheric layer

- Located at about 0-11km (0-7.0 mi)
- Practically all weather occurs in the troposphere
- Temperature generally decreases with height (environmental lapse rate, typical value = 6.5 ^oC/km) – Why??
- Top of troposphere is called the **tropopause**
- Contains 80% of atmospheric mass
- Depth varies with latitude and season



Stratosphere

Stratosphere – The atmospheric layer above the troposphere (2nd layer up)

- Only weather in stratosphere are overshooting thunderstorm tops

- Ozone layer is located in stratosphere
- Temperature increases with height (inversion) – due to O3 absorbtion of UV
- Located from about 11-50 km
- Top of stratosphere is called the **stratopause**
- Contains about 19.9% of atmospheric mass

Mesosphere and Thermosphere

The **mesosphere** (3rd layer up) and the **thermosphere** (4th layer up) contain only 0.1% of atmospheric mass

- Mesosphere located from about 50-80km
- Temperature decreases with height in the mesosphere
- Thermosphere located above 80km
- Temperature increases with height in the thermosphere

Characterizing the Atmosphere Based on Electrical Properties

The **ionosphere** is an atmospheric layer located from the upper mesosphere into the thermosphere

- The ionosphere contains electrically charged particles called ions due to UV radiation
- The ionosphere affects AM radio waves, absorbing them in the day and reflecting them at night
- The ionosphere creates the northern lights (**aurora borealis**) and the southern lights (**aurora australis**) through interactions between the sun's rays and earth's magnetic field

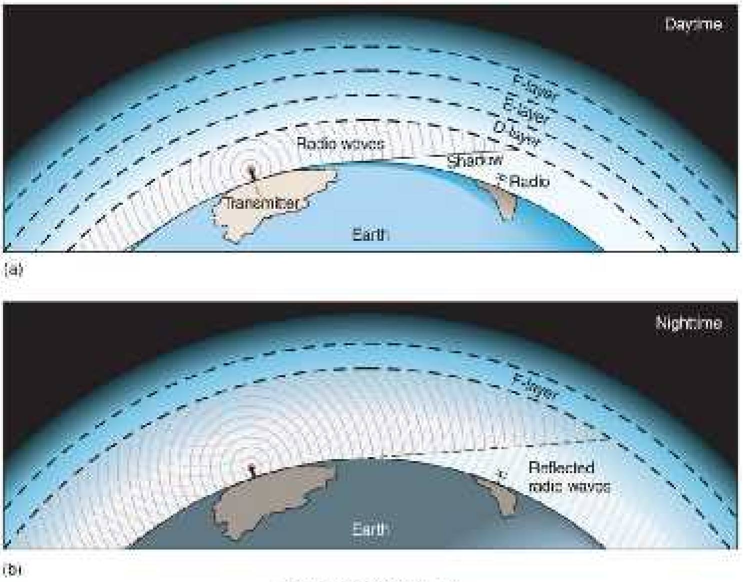


Photo from climate.gi.alaska.edu/Curtis

The Northern Lights