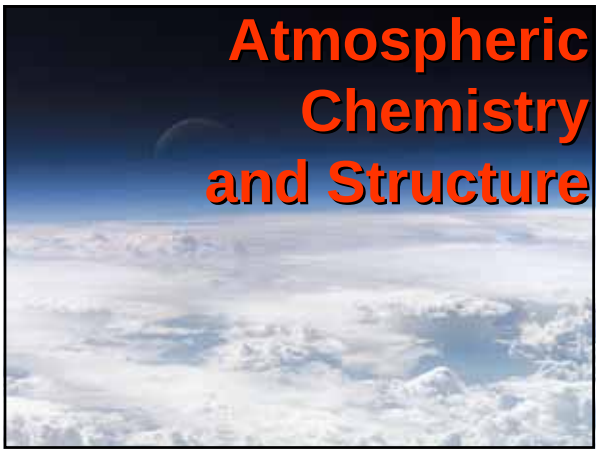
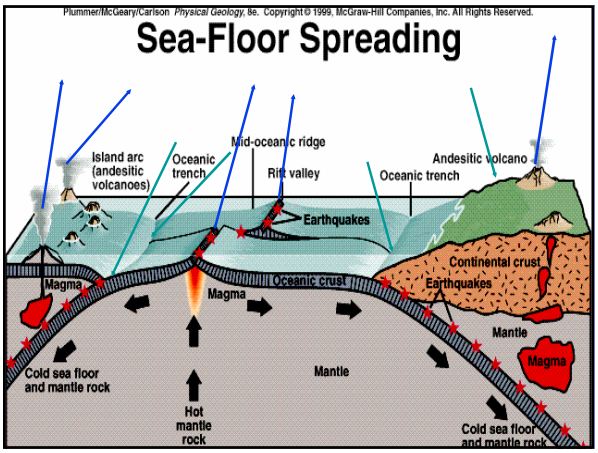
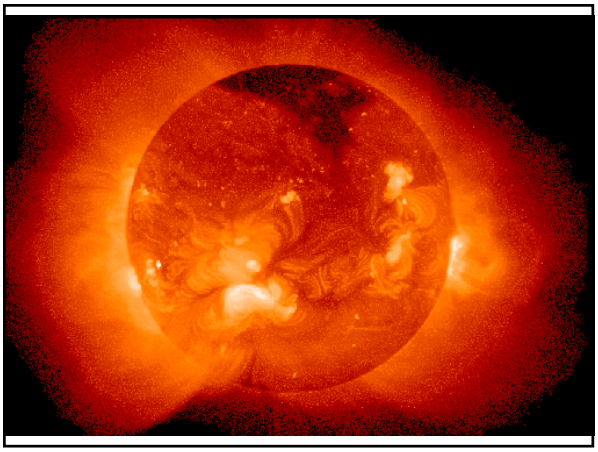


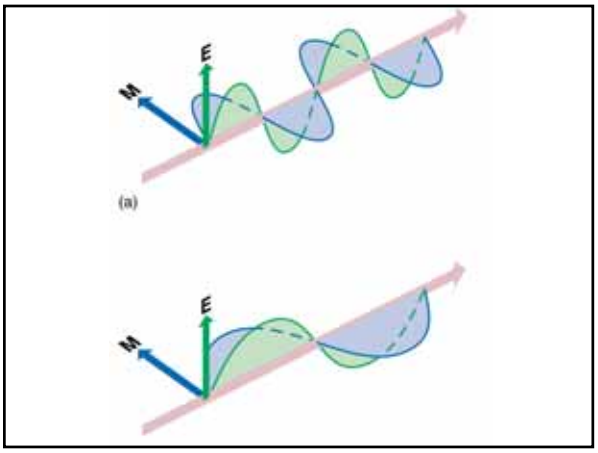

## Atmosphere

- Undergoes rapid frequent changes (weather) in short time scales, but balanced over longer time scales (climate).
- Together with ocean (hydrosphere) it balances energy input from the sun to moderate temperatures on the surface of the planet.



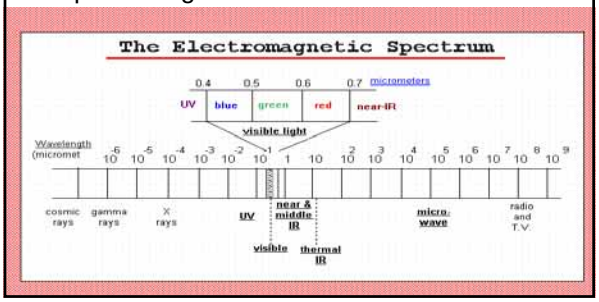
## Radiation

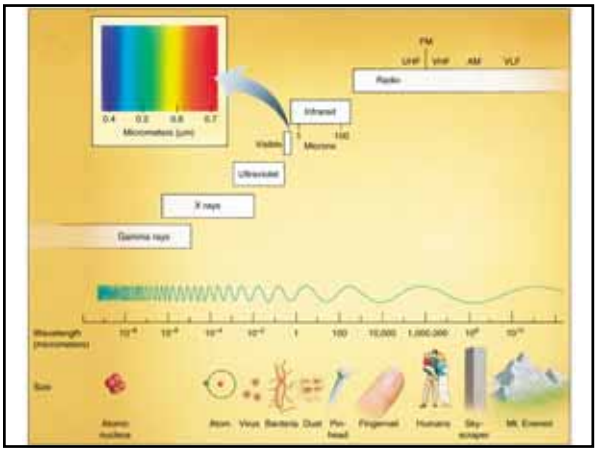
- Only form of energy that can be propagated w/o a transfer medium.
- By far the greatest input of energy to the Earth-atmosphere system.
- Can be represented as a stream of particles or as an electric and magnetic wave system.
- Shorter wavelengths = higher energy photons.

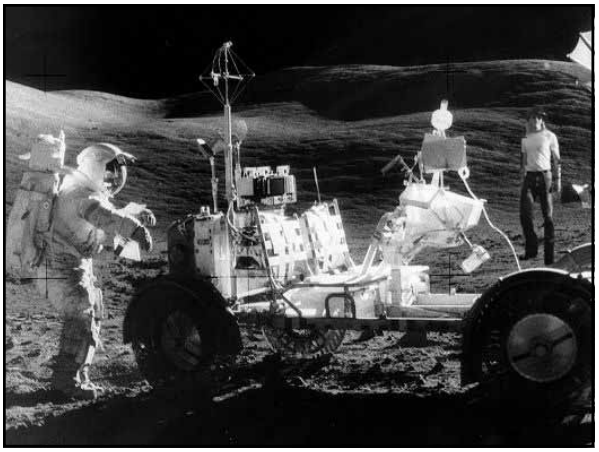


## Electromagnetic Radiation (EMR)

- EMR: energy of a wave in motion at the speed of light.

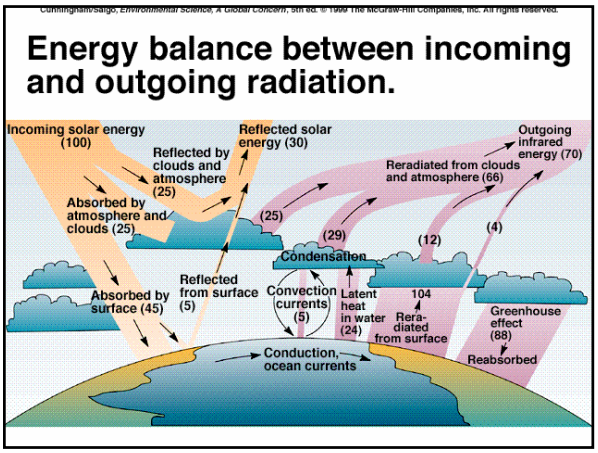


## Energy Balance

- Radiation incoming from the sun.
- 25 % reflected back by atmosphere and 5 % by the surface of earth.
- 25 % absorbed by atmosphere and re-radiated back to space.
- 45 % absorbed by surface of land and water.




## How much solar radiation reaches the ground is dependent on:

1. Solar intensity (increases over geologic scales, fluctuates slightly with sunspot cycle).
2. Distance between Earth and Sun (affects solar constant).
3. Reflection and Absorption by the atmosphere.
4. Angle at which solar rays hit the surface.

## How thick is the atmosphere?

- The total mass of the atmosphere is $5.14X10^{15}$ kg.
- No set definition of the density of gas molecules for “atmosphere”.
- For practical purposes we can say the atmosphere is 100km (60 mi) thick.
- The radius of the Earth is 6500 km.

## Atmosphere composition

- The lower 80km of the atmosphere has a relatively consistent composition = homosphere.
  - Permanent gases and variable gases
- The upper reaches of the atmosphere change to greater amounts of Hydrogen and Helium as you go up = heterosphere.

## Permanent Gases

| Gas | Form | Mass | Volume |
|---|---|---|---|
| • Nitrogen | $N_2$ | 75.5% | 78% |
| • Oxygen | $O_2$ | 23% | 21% |
| • Argon | Ar | most of the rest | |

## %, ppt's, ppm's, ppb's

- percent % =
  (partial quantity/total quantity) X 100
- parts per thousand ppt =
  (partial quantity/total quantity) X 1,000
- parts per million ppm =
  (partial quantity/total quantity) X 1,000,000
- parts per billion ppb =
  (partial quantity/total quantity) X 1,000,000, 000

**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 |

**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 | $CO_2$ | 0.037 | 44.01 |
| Ozone | $O_3$ | 0.01 | 48.00 |

## Variable Gases

### Water

- Concentration decreases with altitude.
  - Most below 5km.
- Approximately 0.25% of atmosphere.
- Residence time approximately 10 days.

## Variable Gases

$CO_2$

- Strong influence on climate.
- Approximately 0.037% of atmosphere.
  - 380 ppm
- Residence time approximately 150 years.

## Variable Gases

Methane – $CH_4$

- Approximately 1.7 ppm of atmosphere.
  - Has been increasing at approximately 0.01 ppm / year recently.
- Residence time approximately 10 days.

## Atmospheric composition

- Aerosols
- Non-gas components
- Small solid particles and liquid droplets
- Also called particulates
- Smallest are 0.01 μm
- Residence time of a few days to several weeks.
- Come out with precipitation.

## Aerosols continued

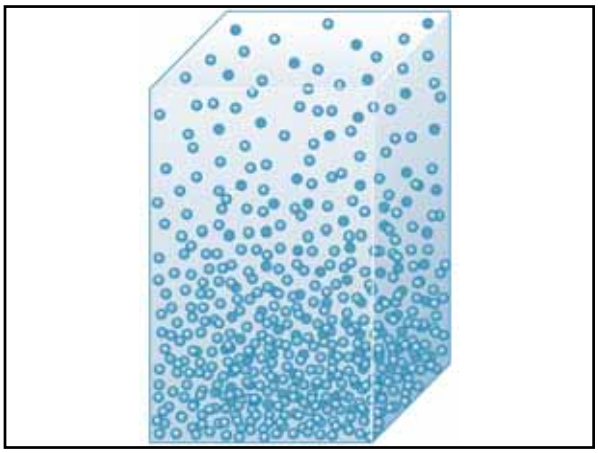
- Major source is chemical conversion of sulfate gases to solids or liquids.
  - Also from wind-generated dust, volcanic ejections, sea spray, and combustion by-products.
- Cause urban smog, reduce visibility.
- Play a major role in cloud formation because they act as condensation nuclei.

## Vertical Structure of the Atmosphere

- We can define the vertical layers in different ways:
  1. Composition
  2. Electrical
  3. Density
  4. Temperature

## Density Structure

- Density reduces rapidly with height.
- Changes more rapidly near sea-level than at higher altitudes.
- At sea-level the density is about 1.2 kg/$m^3$, but at Denver it is about 1 kg/$m^3$.

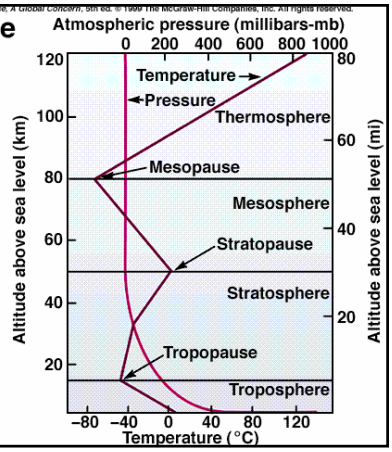


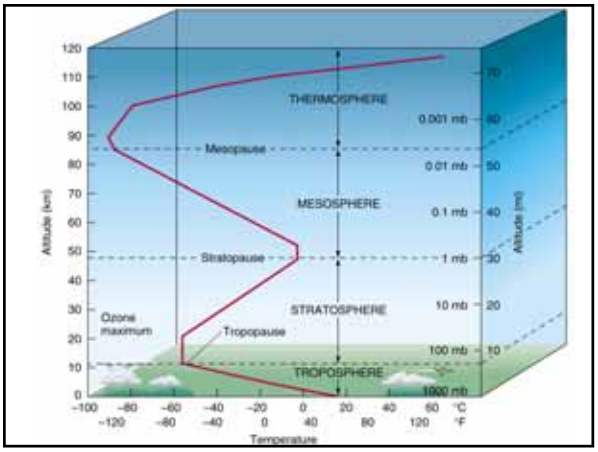
# Layers based on temperature profiles

- Troposphere
  - Bottom layer in which T decreases with altitude
- Stratosphere
  - T increases with altitude
- Mesosphere
  - T decreases with altitude
- Thermosphere
  - Top layer in which T increases with altitude



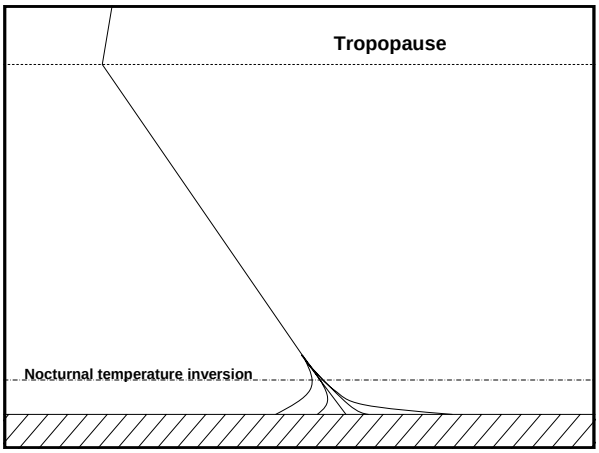
**The atmosphere is layered into four distinct zones of contrasting temperature due to differential absorption of solar energy.**

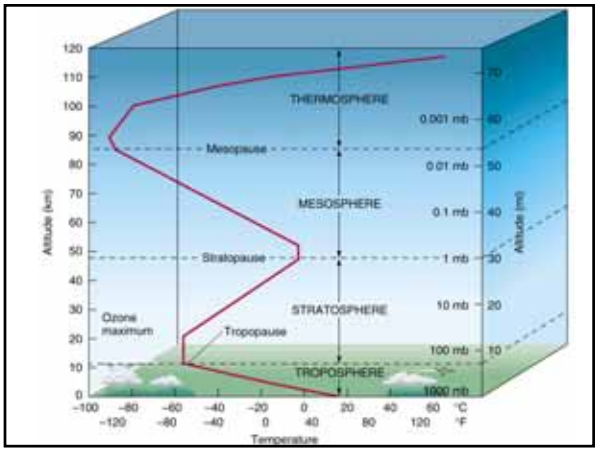



# Troposphere

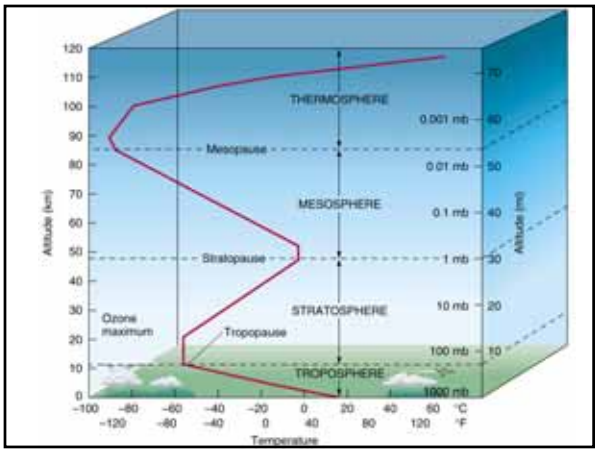
- Has a depth of 8 to 16 km, with an average of 11 km.
- Contains practically all the phenomenon we call “weather”.
- Contains 80% of the mass of the atmosphere.
- Heated from below .
- Average T is 15°C at the base and -50°C at the top.
- Inherently unstable.




# Stratosphere

- 19.9% of the total mass of the atmosphere.
- Base has an average T of -59°C and remains so up to ~20km.
- Above 20km, ozone absorbs UV radiation and causes a warming with altitude.
- Top at 50km has an average T of -2°C.
- Inherently stable.




# Mesosphere

- 50km to 80km
- Of the two remaining layers, it holds 99.9% of the mass.
- Heated at its base by absorption of solar radiation.
- Inherently unstable (heat dispersed upward by vertical air motion).

## Thermosphere

- High energy photons (cosmic rays, gamma rays, and x-rays) absorbed at the top of the atmosphere allow the temperatures to rise to 1500°C.
- Heat content is very low.
- Molecules in the upper thermosphere often travel kilometers before colliding with another particle.
- Ordinary thermometer would not read 1500°C.

## Weather Basics

- Temperature
- Pressure
- Wind
- Humidity