

# 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



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### 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 <sub>2</sub>	78.08	28.01
Oxygen	O <sub>2</sub>	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 <sub>2</sub>	0.00005	2.02

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### 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 <sub>2</sub> O	0.25	18.01
Carbon Dioxide	CO <sub>2</sub>	0.038	44.01
Ozone	O <sub>3</sub>	0.01	48.00

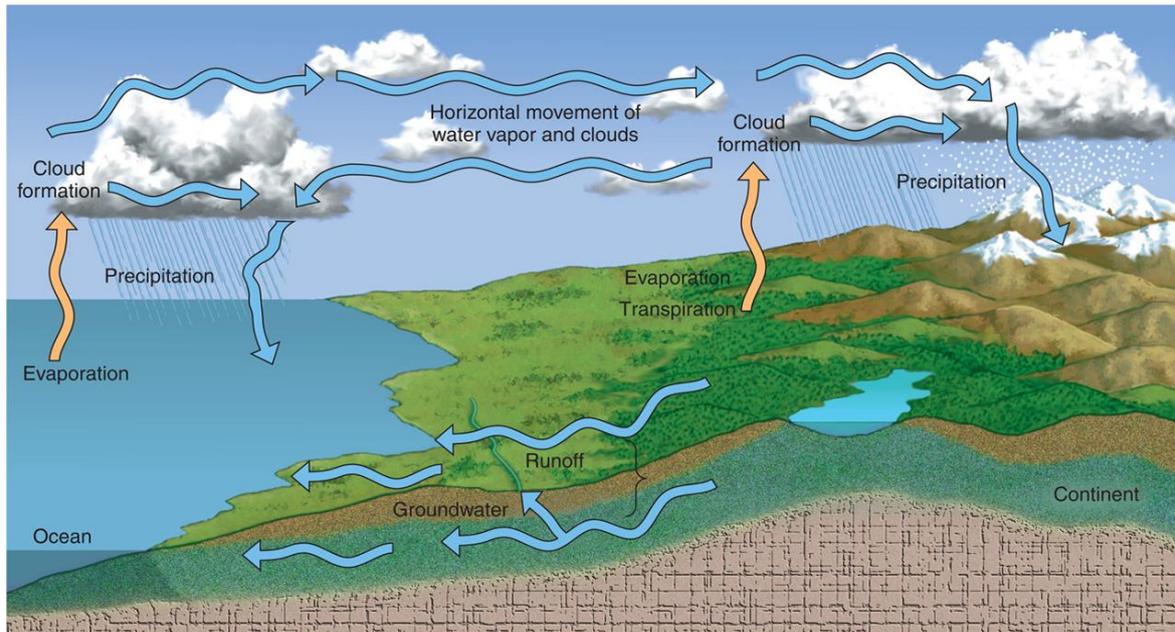
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## Water Vapor

**Water vapor (H<sub>2</sub>O)** – 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

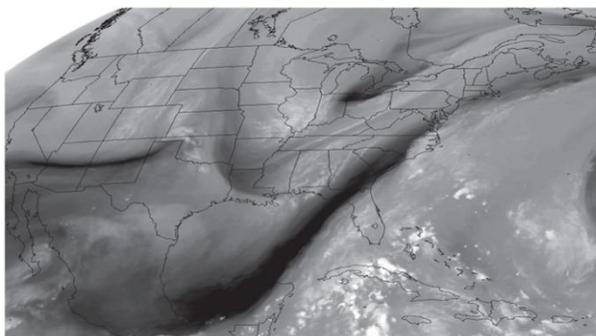


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## Water Vapor Satellite Imagery

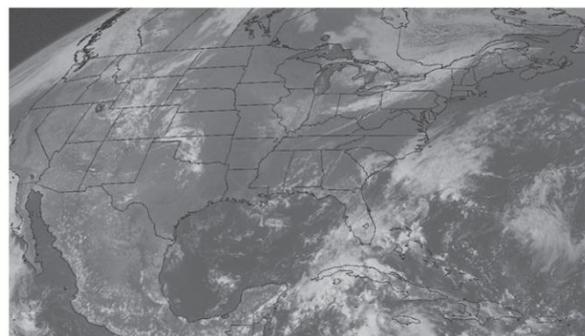
- Satellite imagery reveals variable nature of water vapor concentration
- Water vapor satellite imagery also reveals moist and dry regions of the atmosphere (visible imagery does not)

Water vapor imagery



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Visible imagery



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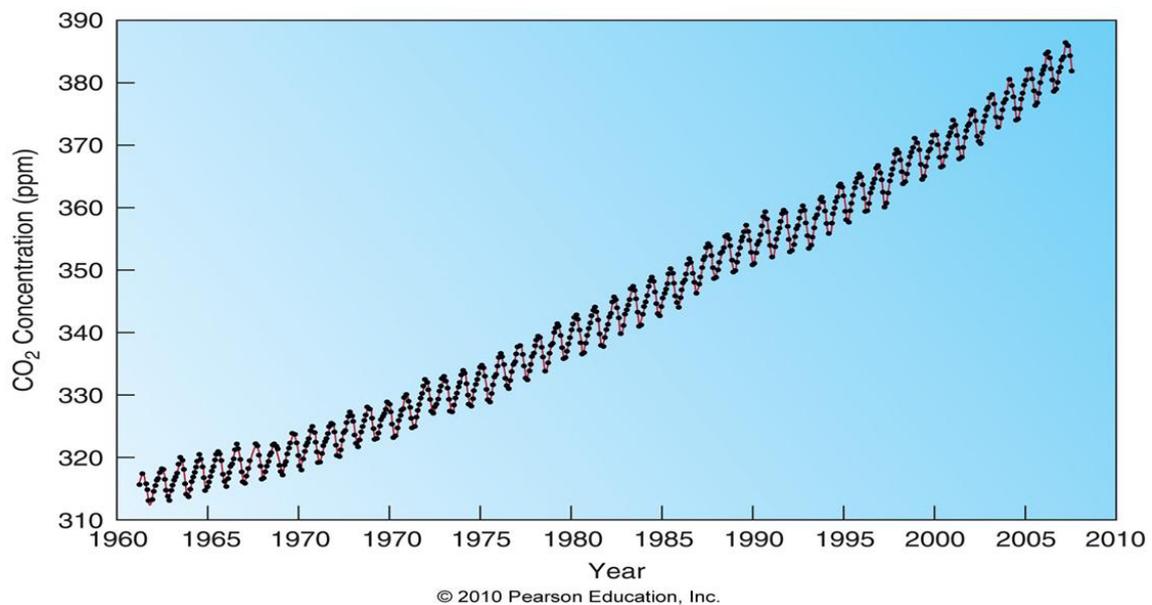
## Carbon Dioxide

- **Carbon dioxide (CO<sub>2</sub>)** – 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<sub>3</sub>)** – A beneficial and harmful variable gas

- O<sub>3</sub> concentrations in the stratosphere (~15-50 km above sea level) are relatively high (15 ppm), occurs from natural chemical reactions



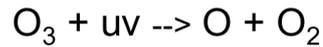
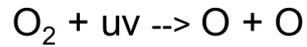
Absorbs UV radiation!!

- O<sub>3</sub> concentration near earth's surface is usually near zero, but can increase to 0.15 ppm through chemical reactions in polluted air

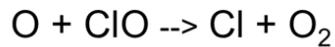
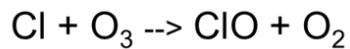
—————→ Irritant!!

### Stratospheric Ozone Creation and Destruction

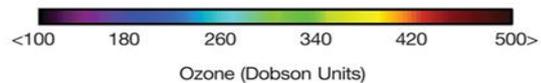
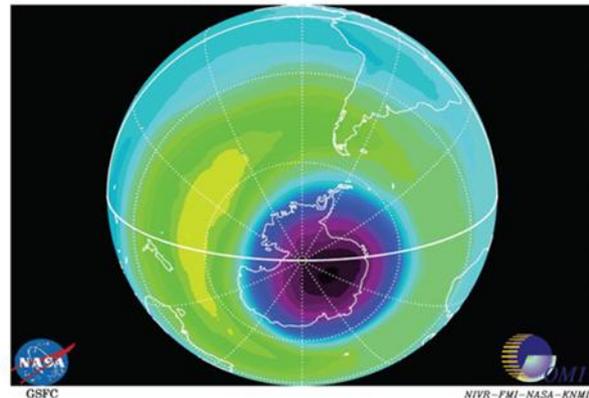
- Natural ozone cycle



- After introduction of CFCs



Nimbus-7 Monthly Average Total Ozone for October 2006



### Methane

- **Methane** (CH<sub>4</sub>) – A variable gas with residence time ~10 years that has high potential for greenhouse warming

Sources - 1) Rice cultivation, wetlands

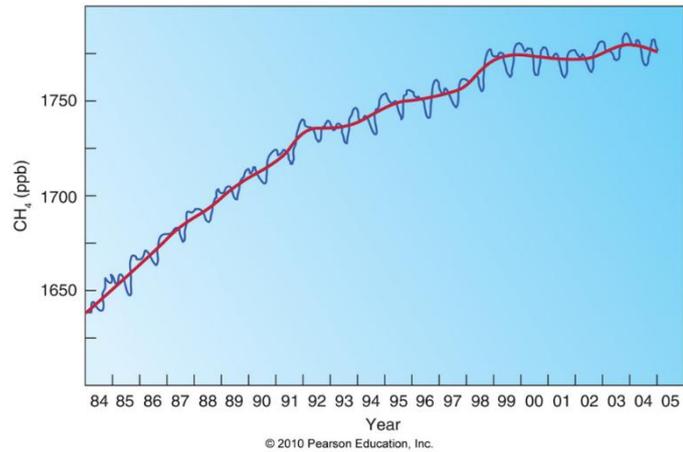
2) Mining

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 =  $1,000/\text{cm}^3$

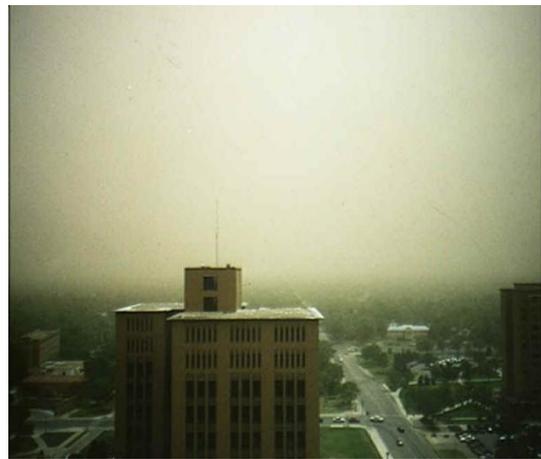
Typical diameter = 10 microns (0.00001 meter)

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



Haboob in Phoenix, AZ



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Forest fire smoke in CA



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

Density of various materials

Water	1000 kg/m <sup>3</sup>
Steel	7800 kg/m <sup>3</sup>
Air (at sea level)	1.2 kg/m <sup>3</sup>

- The atmosphere is compressible
- Density decreases with height

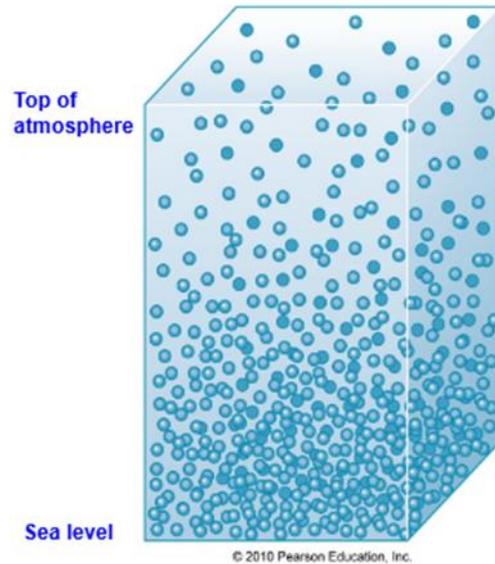
## Atmospheric Pressure

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?

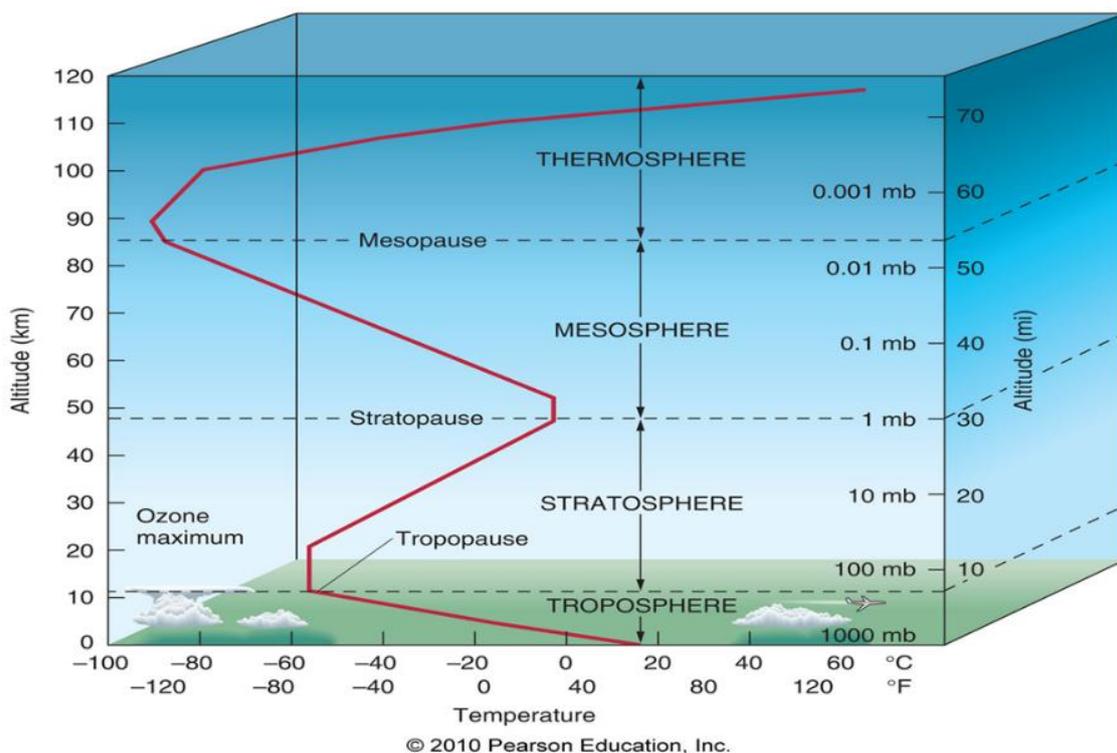
Average sea-level pressure = 14.7 psi  
 = 1013.25 mb  
 = 101325 Pa  
 = 29.92 in Hg  
 = 1 atmosphere



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 (°F), Celsius (°C), or Kelvin (K)

### Conversions

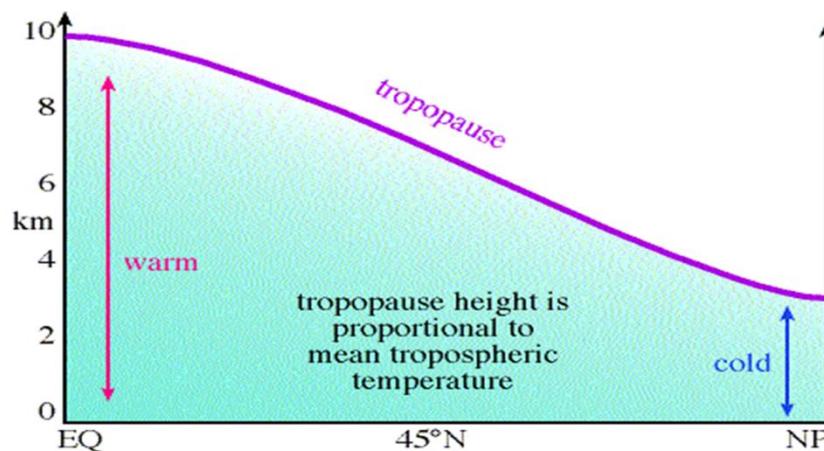
$$K = ^\circ C + 273.16$$

$$^\circ F = (9/5) * ^\circ C + 32$$

## 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 °C/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 O<sub>3</sub> absorption 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**

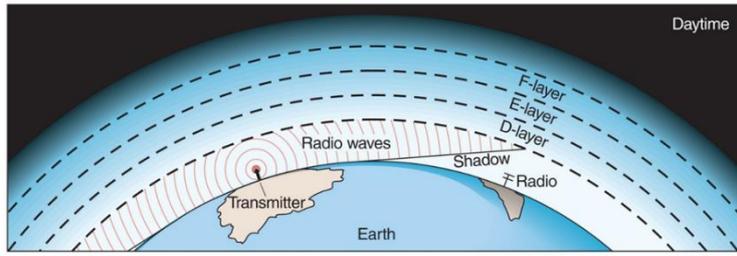
The **mesosphere** (3rd layer up) and the **thermosphere** (4th layer up) contain only 0.1% of atmospheric mass

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

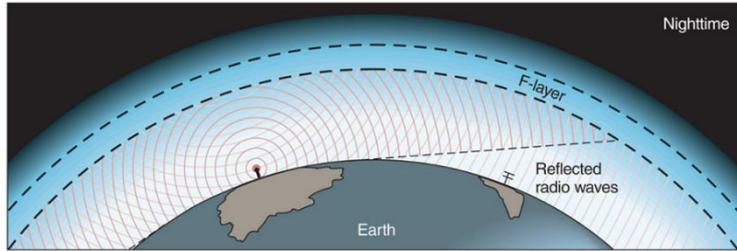
### **Characterizing the Atmosphere Based on Electrical Properties**

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



(a)



(b)

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**The Northern Lights**

Photo from [climate.gi.alaska.edu](http://climate.gi.alaska.edu/)/Curtis