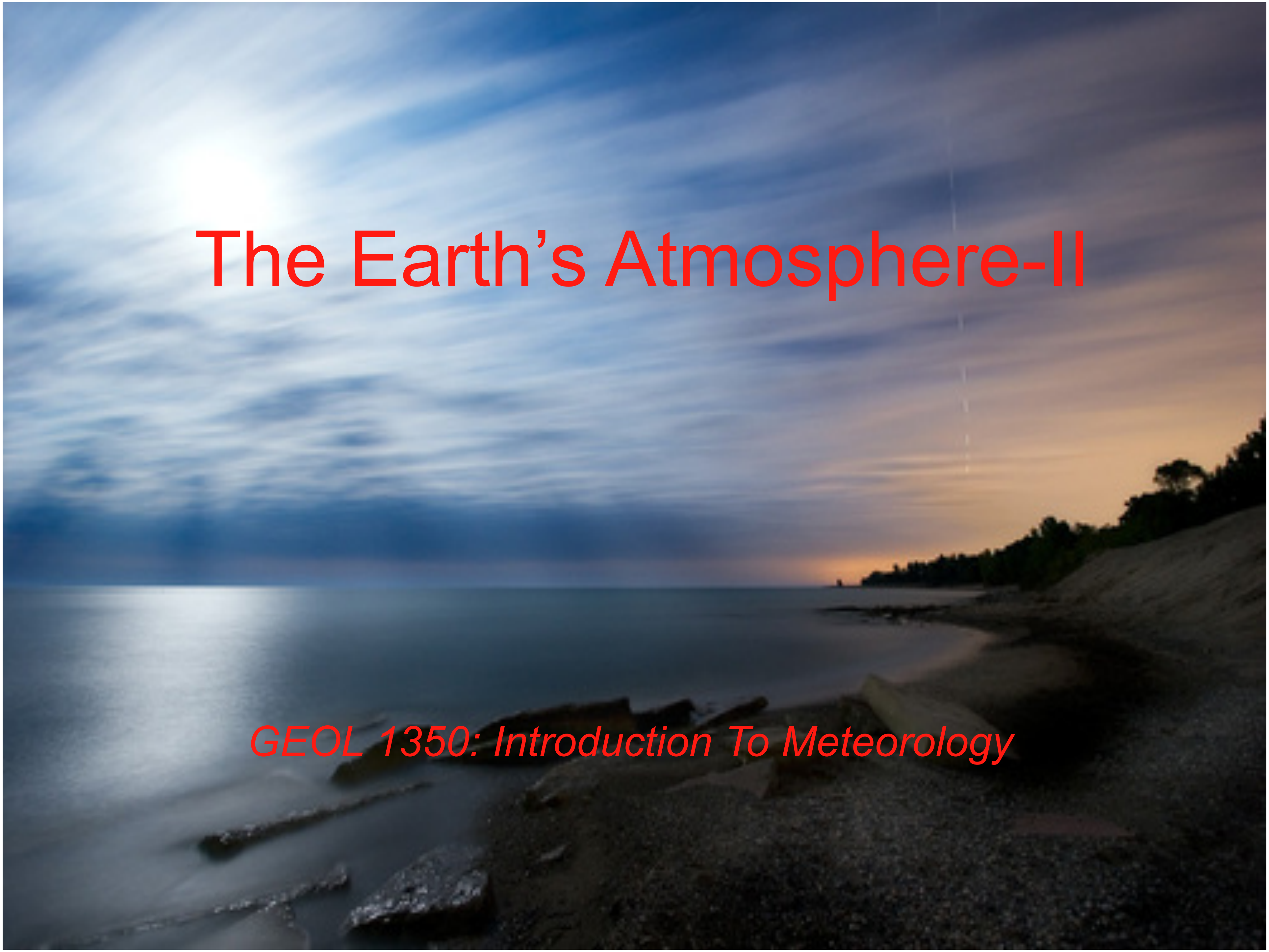


The Earth’s Atmosphere-II

GEOL 1350: Introduction To Meteorology

Vertical Structure of Atmosphere

- Vertical profile of the atmosphere reveals that it can be divided into a series of layers.
- Each layer may be defined in a number of ways:

1. by the air temperature varies through it
2. by the gases that comprise it

- Before examining various layers, we need to look at the vertical profiles of air pressure and air density.

Air Density

- **Air molecules are held near the earth by gravity.**
- **This strong, invisible force pulling down by the air above compresses air molecules closer together, which causes their number in a given volume to increase.**
- **More air above a level, the greater the squeezing effect or compression.**
- **Air density is defined as the number of air molecules in a given space (volume).**

Air Pressure

- **Air molecules have weight.**
- **The weight of all the air around the earth is 5600 trillion tons.**
- **The weight of air molecules acts as a force upon the earth.**
- **The amount of force exerted over an area of surface is called atmospheric pressure or air pressure.**
- **The pressure at any level in the atmosphere may be measured in terms of the total mass of the air above any point.**

Air Pressure

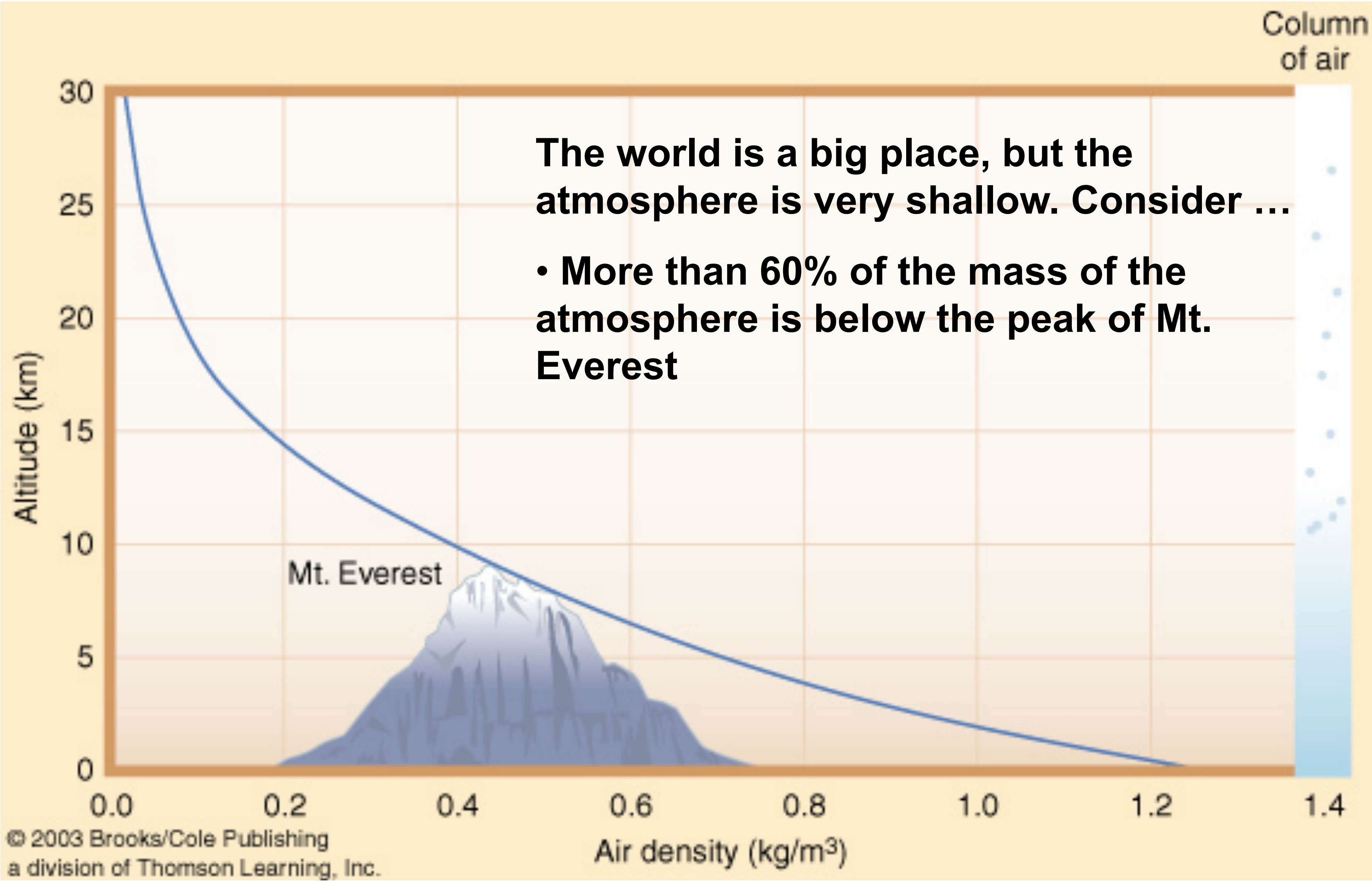
- A column of air one square inch would weight nearly 14.7 pounds.
- Normal atmospheric pressure near sea level is close to 14.7 pounds per square inch.
- If more molecules are packed into the column, it become more dense, the air weights more, and the surface pressure goes up.
- If fewer molecules are in the column, the air weights less, and the surface pressure goes down.
- Change in the air density can bring a change in air pressure.

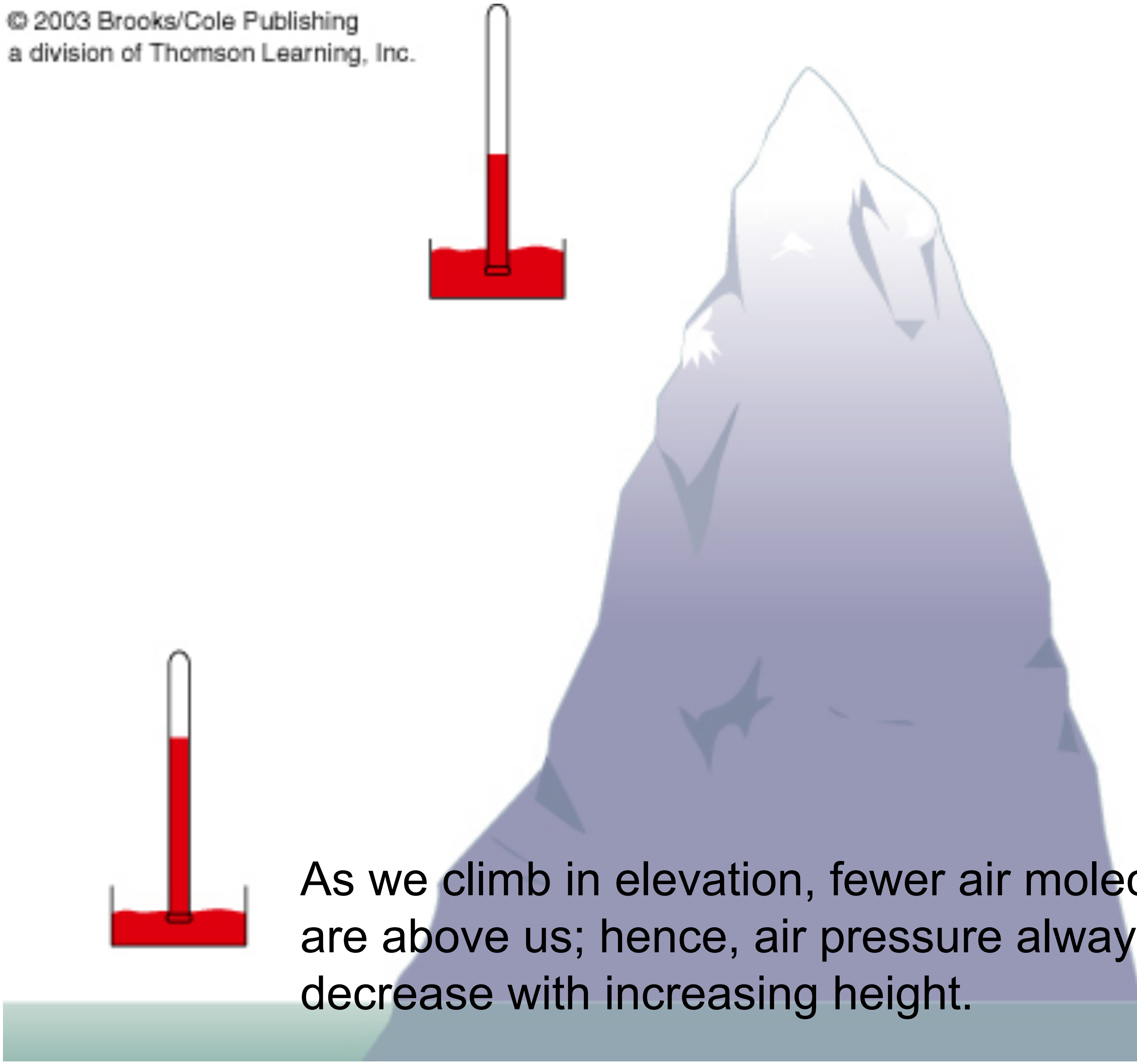
Air Pressure

- **Most common unit for air pressure found on the surface weather maps is millibar (mb) and hectopascal (hPa).**
- **At sea level, the standard value for atmospheric pressure is**
- **1013.25 mb = 1013.25 hPa = 101325 Pa**
- **1 mb = 1 hPa = 100 Pa**

The world is a big place, but the atmosphere is very shallow. Consider …

- More than 60% of the mass of the atmosphere is below the peak of Mt. Everest





As we climb in elevation, fewer air molecules are above us; hence, air pressure always decrease with increasing height.

Standard Sea-Level Pressure

- 101.325 kPa
- 1013.25 hPa
- 101,325 Pa
- 101,325 N/m^2

Atmospheric Pressure at altitude z

$$P = P_o e^{-(a/T)z}$$

Pressure decreases approximately exponential with height

a = 0.0342 K/m
e = 2.71828

T = in Kelvin
z in m

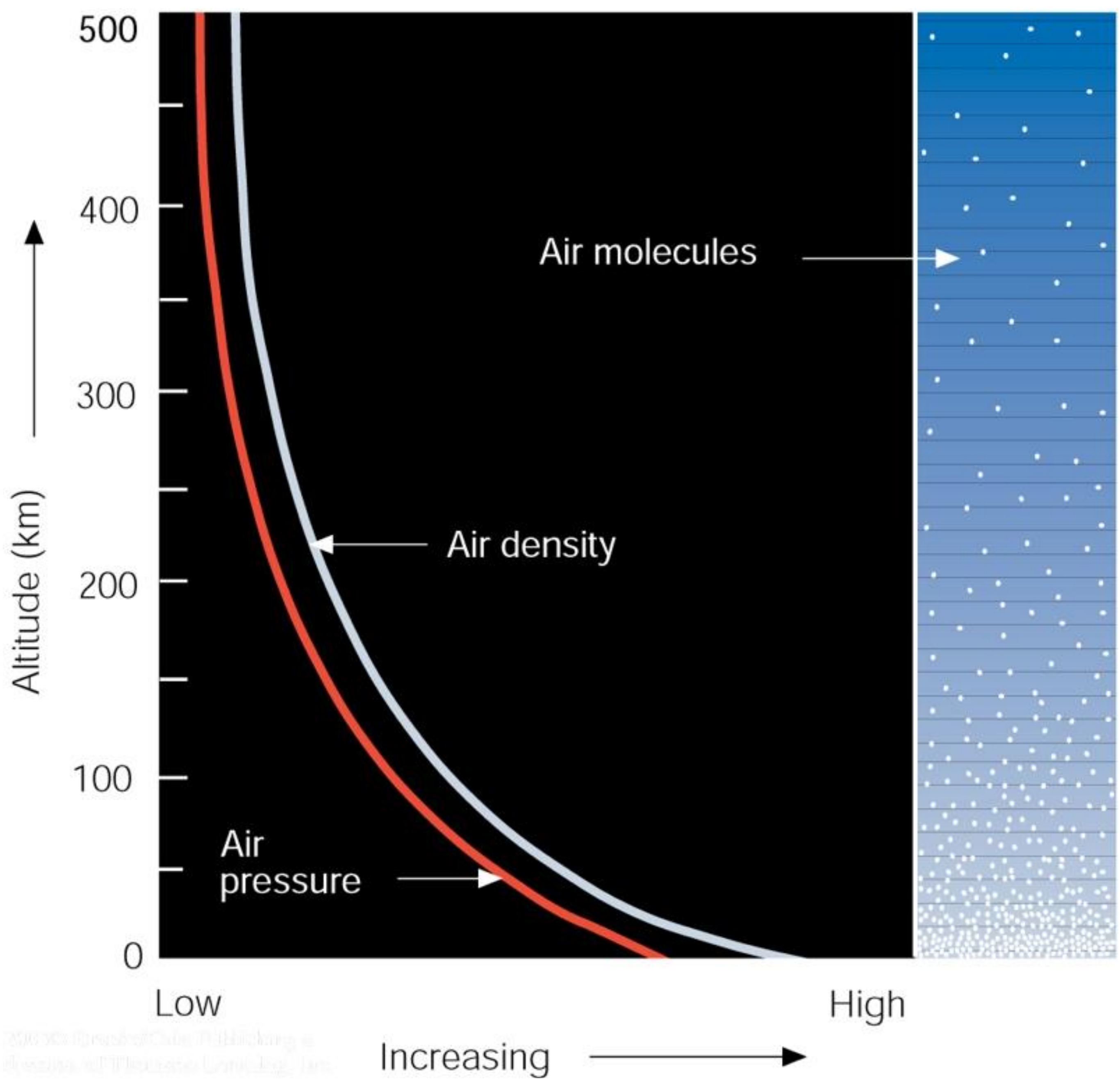
$$P = P_o e^{-z/H_p}$$

$$H_p = 7.29\,km = 7290m$$

Scale height, or
e-folding distance of pressure

What is the air pressure at a height of 20 km? Sea Surface Pressure is 101325 Pa. Scale height is 7.29 km.

$$P = P_0 \bullet e^{-z/Hp} = 101325 \bullet e^{-20/7.29} = 6519.83 \text{ Pa}$$



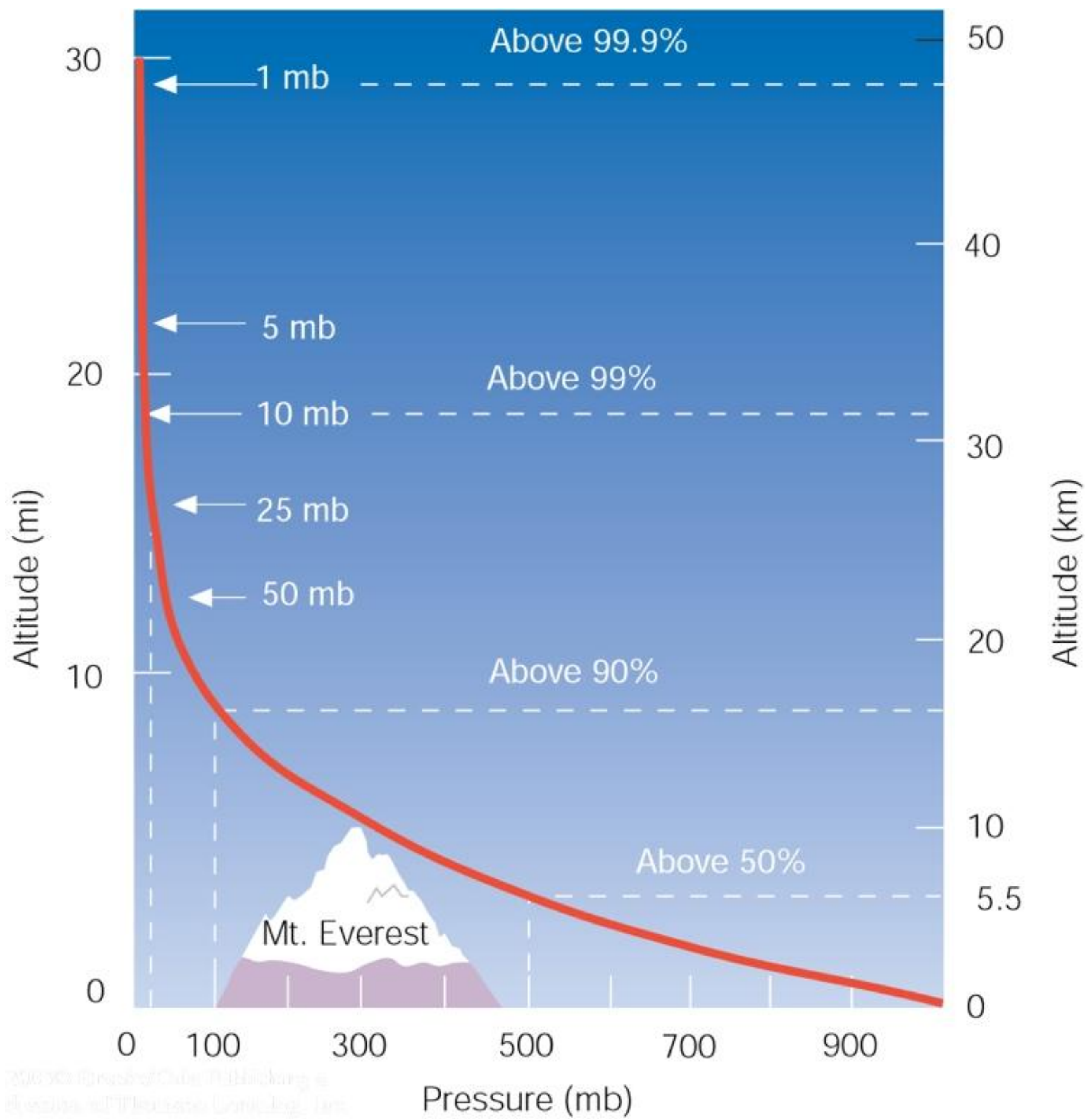
Pressure & Density

Gravity pulls air molecules toward earth's surface

Air density and pressure always decrease as we move up into the atmosphere – they decrease rapidly at first, then more slowly at higher levels

Pressure decreases exponentially with height, but near the surface a linear estimate of 10 hPa per 100 meters works well.

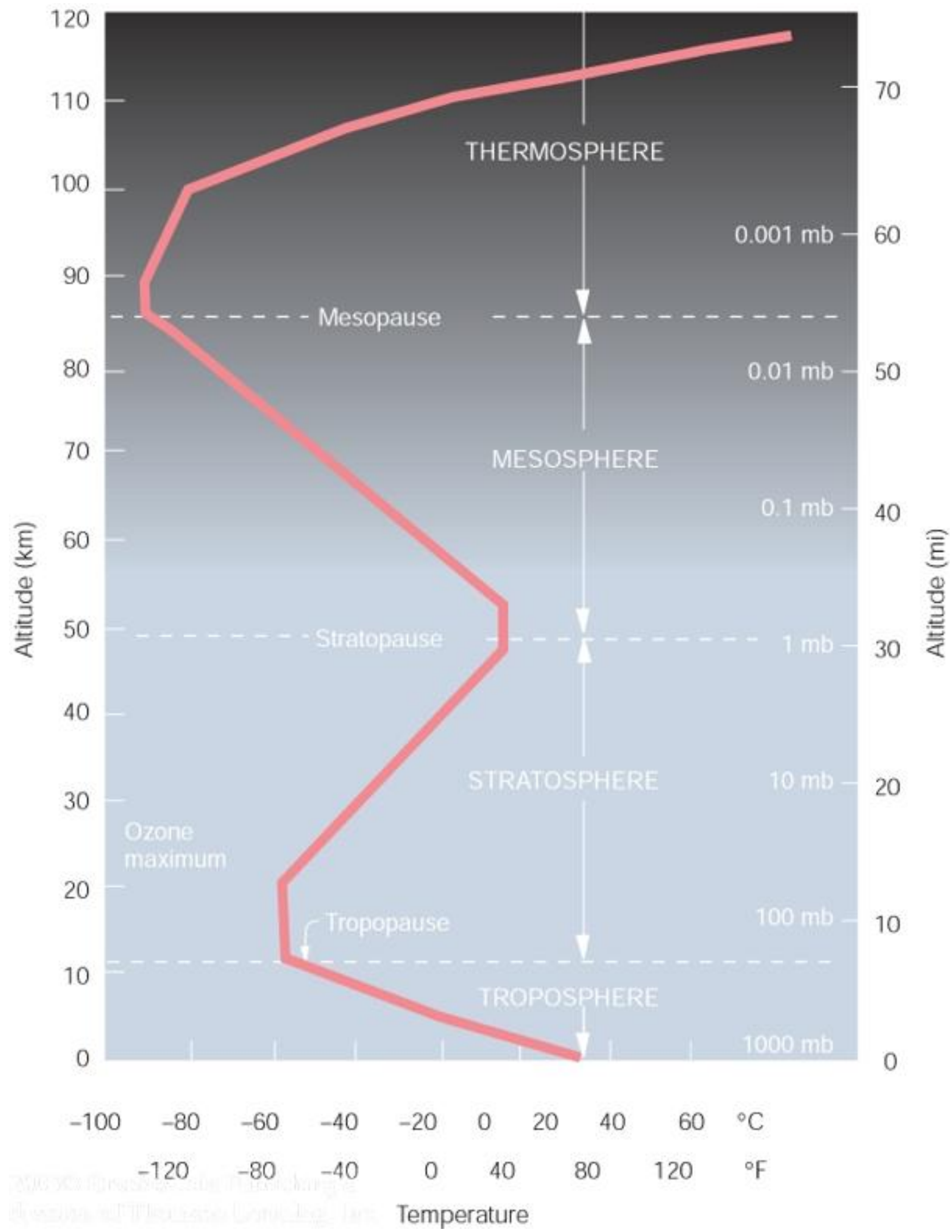
99.9% atmosphere lies below 30 km!



Dividing up the atmosphere

- Variation of T with altitude is used to define distinct layers within the earth's atmosphere

- No other parameter shows as distinct layering as T



Thermosphere (85-500km): T increases with height. Absorption of highly energetic solar radiation by the small amount of residual oxygen.

Mesosphere (50-85 km): T decreases with height. No O_3 heating.

Stratosphere (11-50km); T increases with height as results of absorption of solar UV by stratospheric ozone.

Troposphere (0-11 km): T decreases with height at a rate of 6.5 K/km. Driven by surface heating.

Troposphere (0 ~11 km)

- Name means "mixed"
- Active weather
- Most water vapor and clouds
- Lapse rate (the rate of temperature decreasing with increasing height) = ~ 6.5 ^{o}C km^{-1}
- *Tropopause* (the top of the troposphere) at ~ 8-12 km, 220 hPa
  - 78% mass in troposphere
- All life in or below

Stratosphere (11 ~ 50 km)

- Gradual increase in T caused by absorption of solar radiation by trace gases, mainly ozone
- Name means “layered”
- Weak vertical mixing, few clouds
- *Stratopause* at ~50 km or 1 hPa
  - 99.89% of atmosphere below

Mesosphere (50-85 km)

- **Name means "middle"**
- **Very little heat input from the sun**
- **Coldest layer: -86 C**
- **Earth looses infrared energy from this layer**
- ***Mesopause* at ~ 85 km or 0.37 Pa**
  - **$<4 \times 10^{-4}$ % of atmosphere above**

Thermosphere (85~ 500 km)

- Density is very low
- ‘Temperature’ increases rapidly (absorption of solar ray by O_2 molecules)
- Transition to exosphere

Exosphere (> 500 km)

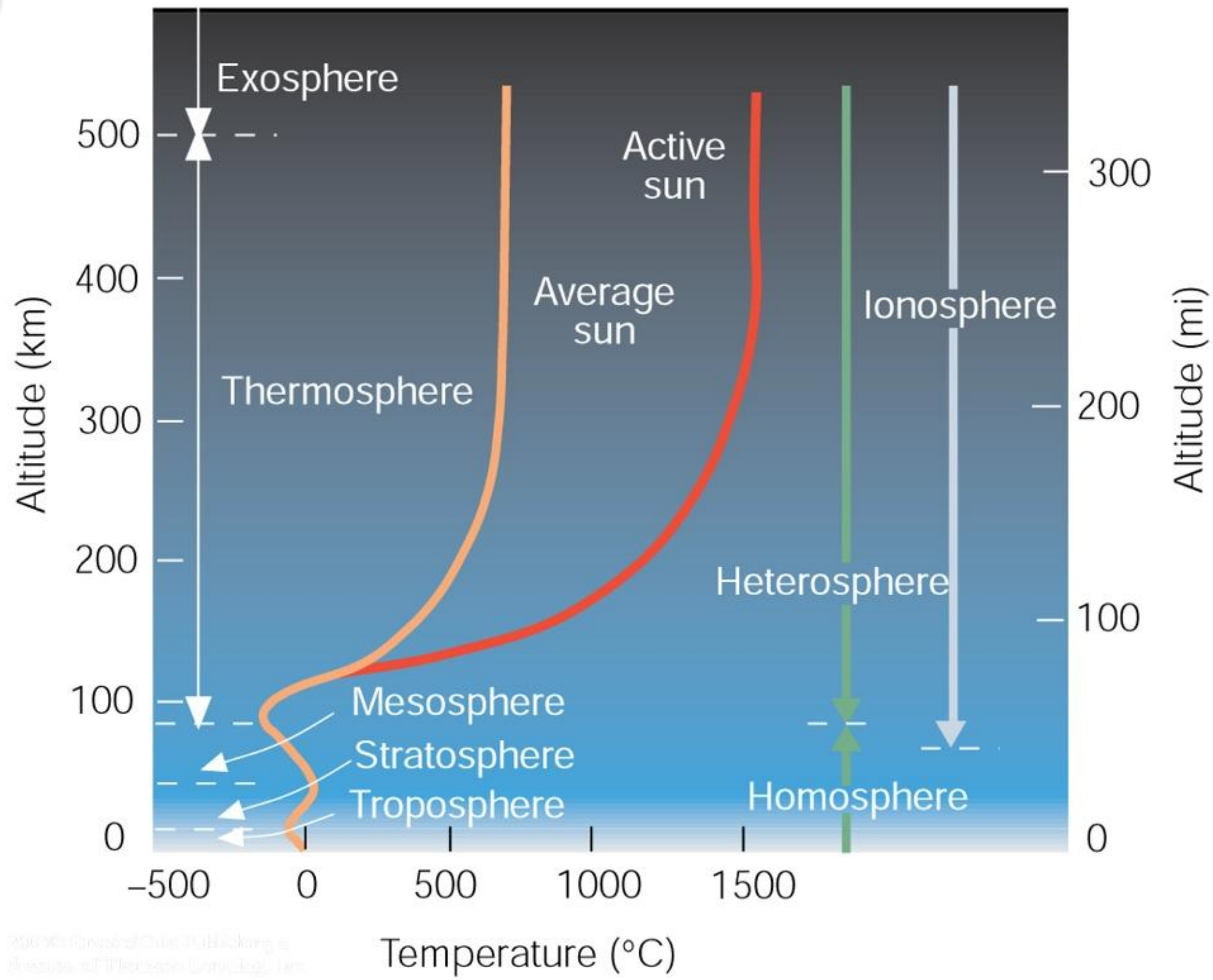
- Transition from atmosphere to outer space
- Molecules with speed (~ 11 km s^{-1}) and direction can escape the earth's gravitational force entirely into deep space.

Other definition of layers based on atmospheric Mixture & Charge

a) Homosphere (0 ~ 85 km) - fairly uniform composition

b) Heterosphere (85 ~ 500 km) - poorly mixed

c) Ionosphere (> 60 km) - electrically charged. Major role in radio communication



Other Layers

- ***Homosphere*** **- uniform composition ~85 km**
- **Gases are well mixed**
- **Chemical composition of the atmosphere does not depend on molecular weight because the gases are mixed by turbulences.**
- **It includes the troposphere, stratosphere, and mesosphere.**

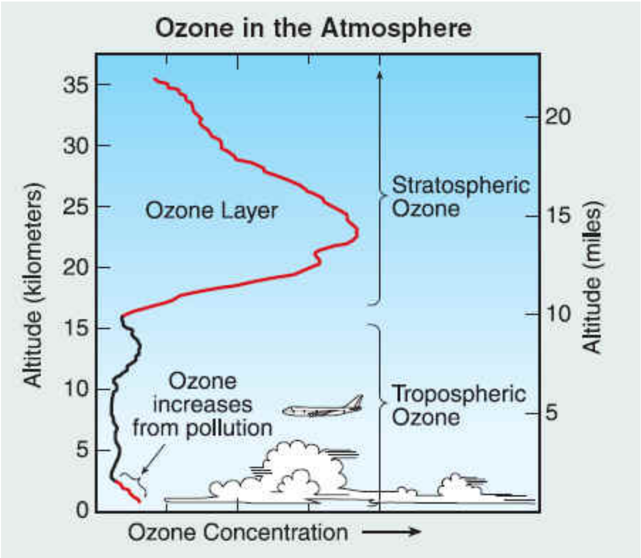
Other Layers

- ***Heterosphere*** **- lighter molecules increasingly more abundant above 85 km**
- **Atmospheric composition varies with altitude.**
- **Distance that particles can move without colliding with one another is larger than the size of motion that cause mixing.**
- **This allow the gases to stratify by molecular weight, with the heavier (lighter) ones present in the bottom (top) of the heterosphere.**

Other Layers

- ***Ozonosphere*: 11 - 60 km**
  - **Peak O_3 = 12 ppm @ 30 km**
  - **Mean O_3 = 6 ppm**

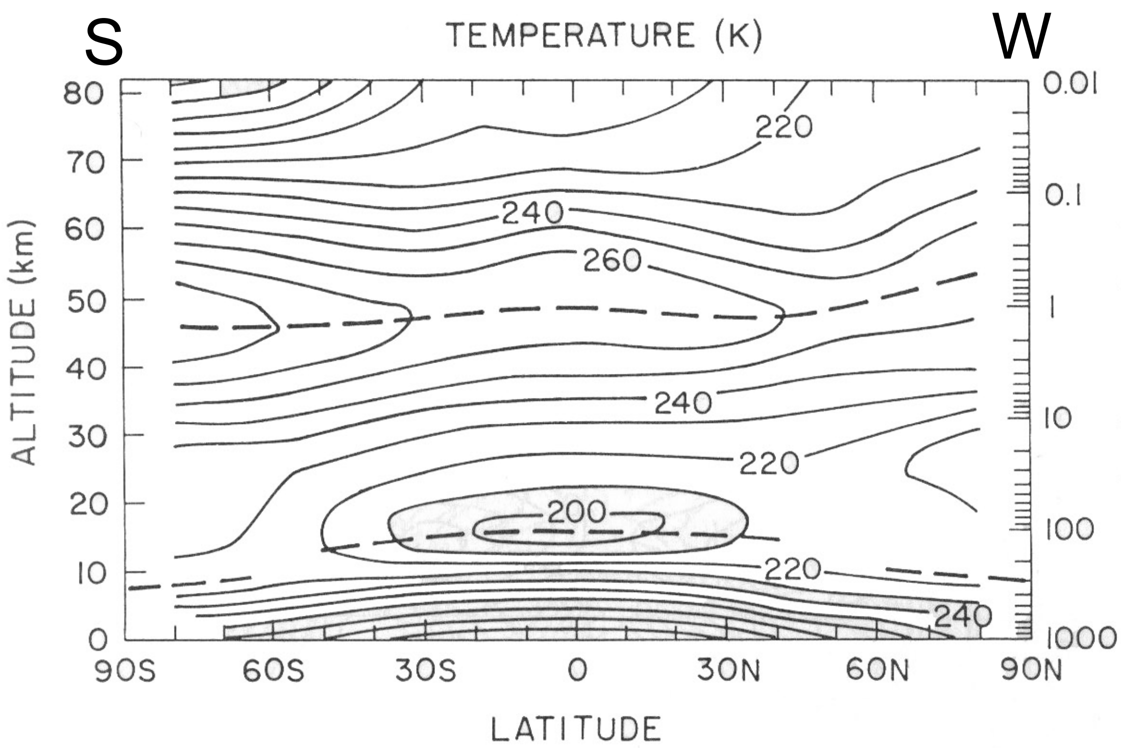
- ***About 90% of the ozone is contained in this layer.***



Other Layers

- ***Ionosphere*: 60 - 180 km**
  - **Molecules and atoms ionized by solar UV radiation**
  - **Reflects radio-waves**
- ***Inonsphere* is not really a layer. It is an electrified region where large concentrations of ions and free electrons exist.**
- ***Ions are atmos and molecules that have lost (or gained) one or more electrons.***

Thermal Structure



Stratopause

Tropopause

Troposphere: T decreases with altitude and latitude.
Tropopause: Highest in the tropics (~16km) and lowest in the polar region (~8km).
Stratosphere: T increases with altitude. Warmest (Summer Pole), Coldest (Winter pole).

Tropopause Height

- **Lapse Rate: The region of the atmosphere where lapse rate changes from positive (in the troposphere) to negative (in the stratosphere) is defined as tropopause.**

- **Chemical Composition: O_3 (H_2O) is higher in the stratosphere (troposphere) and lower in the troposphere (stratosphere).**

- **Potential Vorticity: Dynamical tropopause lies at 2 *potential vorticity unit* (PVU) or 1.5 PVU surfaces.**

Vorticity

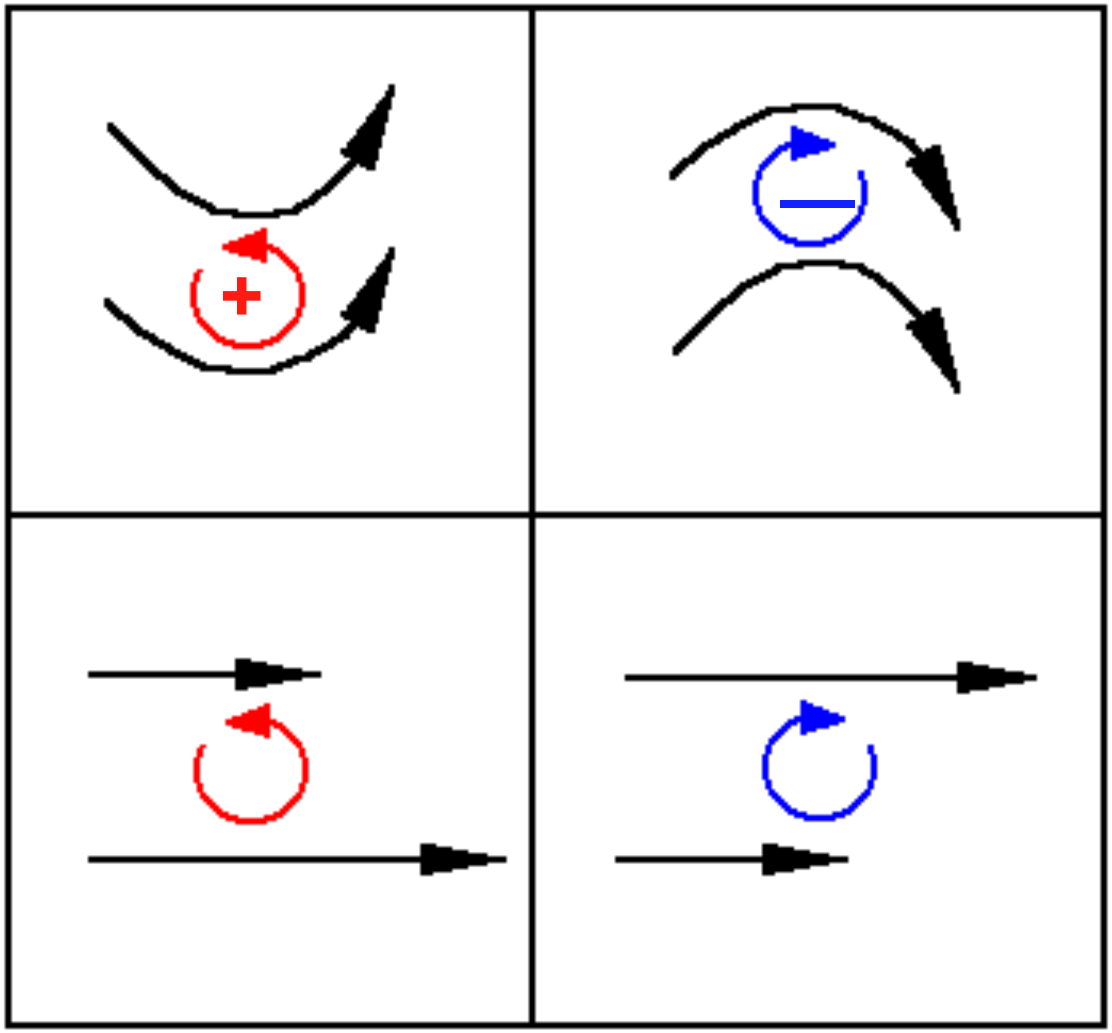
Vorticity is a concept used in fluid dynamics.

It is the tendency for elements of the fluid to "spin".

If a parcel has a counterclockwise spin, it has a positive vorticity.

If a parcel has a clockwise spin, it has a negative vorticity

Vorticity



Counterclockwise Clockwise

Vorticity

by Ellen Levy Finch

If a parcel spin faster, it has a larger absolute value of vorticity.

Potential Vorticity

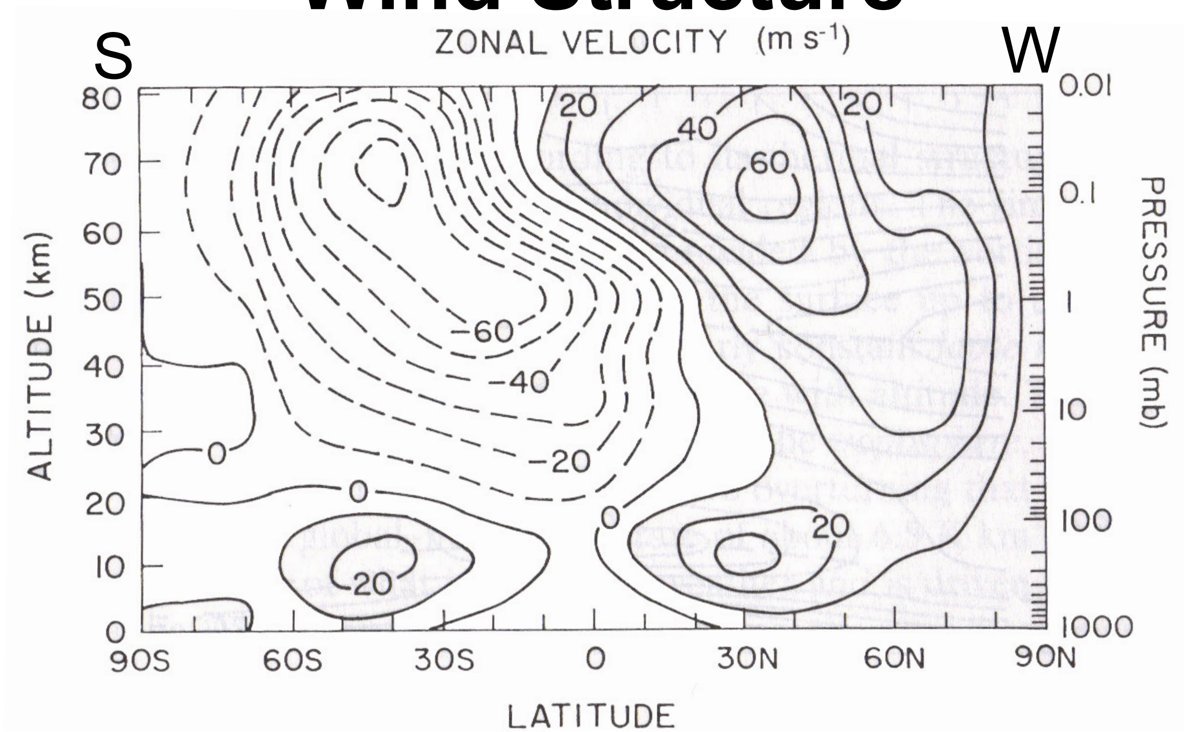
- **Potential Vorticity (PV) is a quantity which is proportional to vorticity.**
- **It is a useful concept for understanding the generation of vorticity.**
- **It is also useful in tracing intrusions of stratospheric air deep into the troposphere in the vicinity of jet streaks.**

Mathematically, one form of potential vorticity is given by the equation:

$$\mathrm{PV} = \frac{1}{\rho}\zeta\,.\nabla\theta$$

where ϱ is the fluid density, ζ is the absolute vorticity and $\nabla\theta$ is the gradient of the potential temperature.

Wind Structure



Subtropic jet streams strengthen with altitude up to the tropopause. These jets describe circumpolar motion that is westerly in each hemisphere.

Above subtropic jets:

In the winter hemisphere, westerly intensifies above the tropopause in the polar-night jet.

In the summer hemisphere, westerly weakens above the tropopause and is then replaced by easterly flow that intensifies up to the mesosphere.

Summary

- **Atmospheric pressure at any level represents the total mass of air above that level.**
- **Atmospheric pressure always decreases with increasing height above the surface.**
- **The atmosphere is divided into different layers according to how the air temperature changes.**

1. **Troposphere – T decreases with height, almost all weather events occur**
2. **Stratosphere – T increases with height, ozone protects us from a portion of the sun's harmful rays**
3. **Mesosphere – T drops dramatically with height, the coldest layer**
4. **Thermosphere – T increases with height, the hottest layer**
5. **Exosphere – lighter particles can escape to outer space**