Bharathidasan University

Programme: MSc Environmental Science and Sustainable Management

Course Title: Principles of Environmental Science and Sustainable Development
Course Code: 21PGCC01
Unit- II Atmosphere
Class 1

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Atmosphere:Composition, Structure, circulation, stability

The Earth and its Atmosphere

This chapter discusses:

1. Gases in Earth's atmosphere
2. Vertical structure of atmospheric pressure & temperature
3. Types of weather & climate in the atmosphere

Solar Energy as Radiation

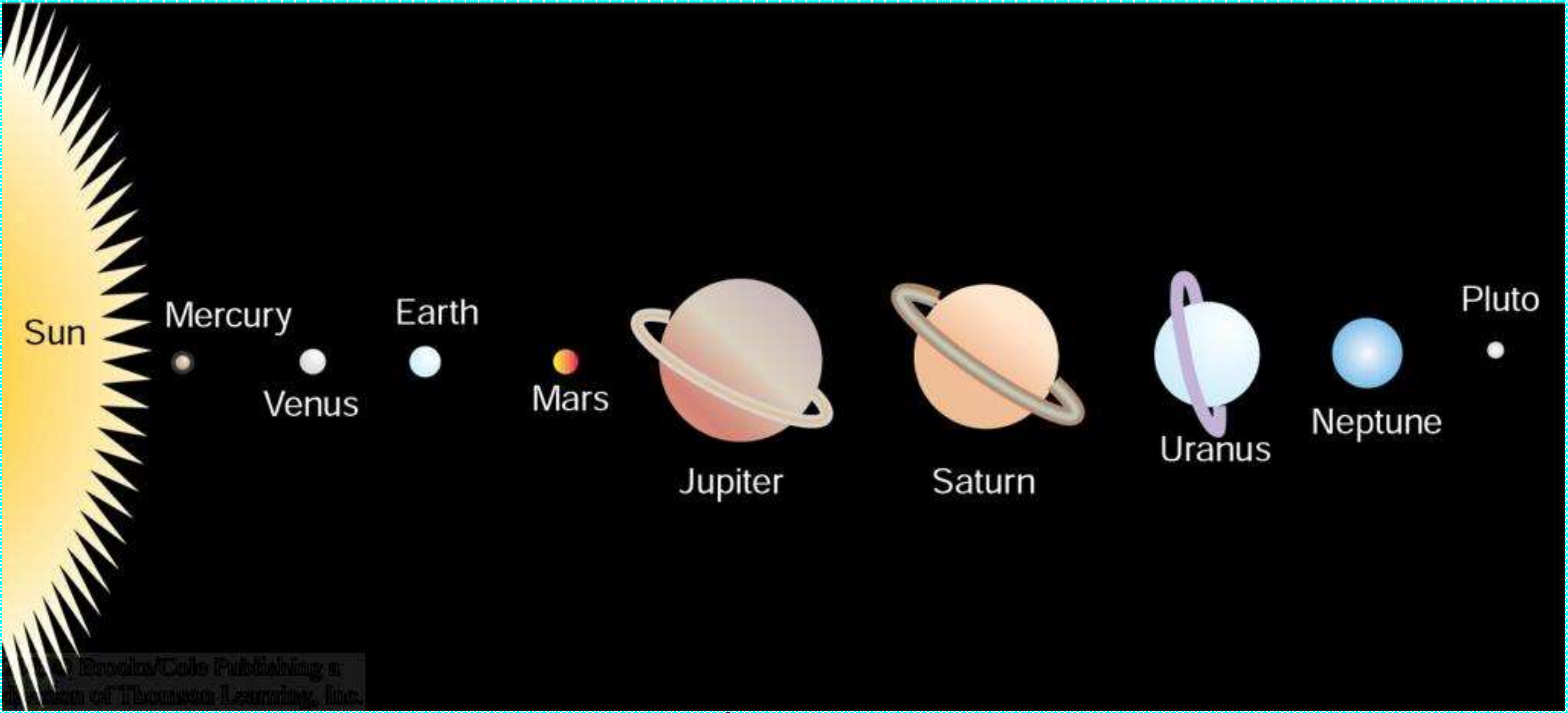


Figure 1.1

Nearly 150 million kilometers separate the sun and earth, yet solar radiation drives earth's weather.

Earth's Atmosphere

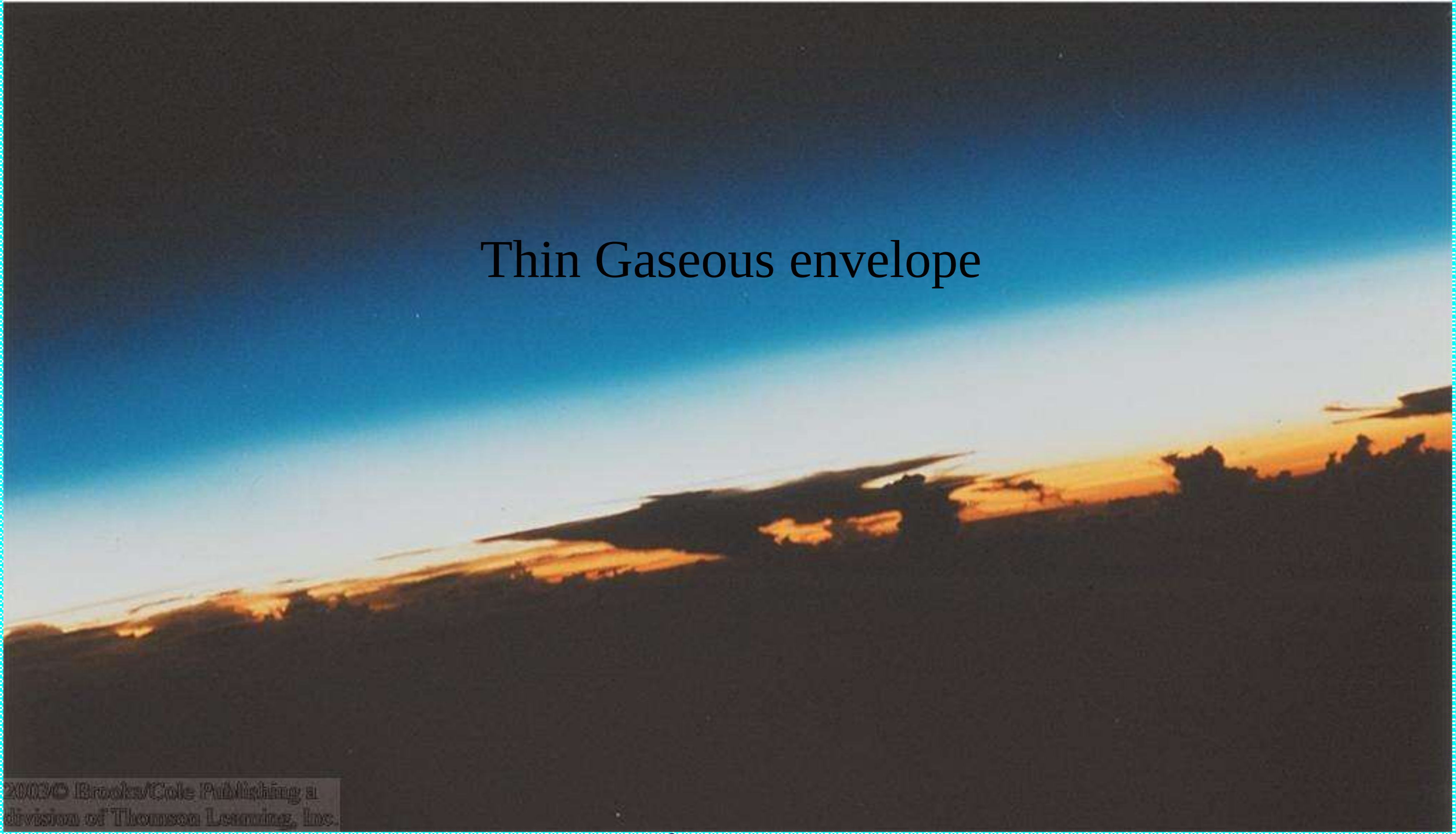


Figure 1.2

99% of atmospheric gases, including water vapor, extend only 30 kilometer (km) above earth's surface.

Most of our weather, however, occurs within the first 10 to 15 km.

Composition of Atmosphere

- **Nitrogen - 78%**
- **Oxygen - 21%**
- **Water Vapor – 0 to 4%**
- **Carbon Dioxide - .037%**
- **Other gases make up the rest**

Atmospheric Gases

Nitrogen, oxygen, argon, water vapor, carbon dioxide, and most other gases are invisible.

Clouds are not gas, but condensed vapor in the form of liquid droplets.

Ground based smog, which is visible, contains reactants of nitrogen and ozone.

Ozone – is the primary ingredient of smog!

Variable & Increasing Gases

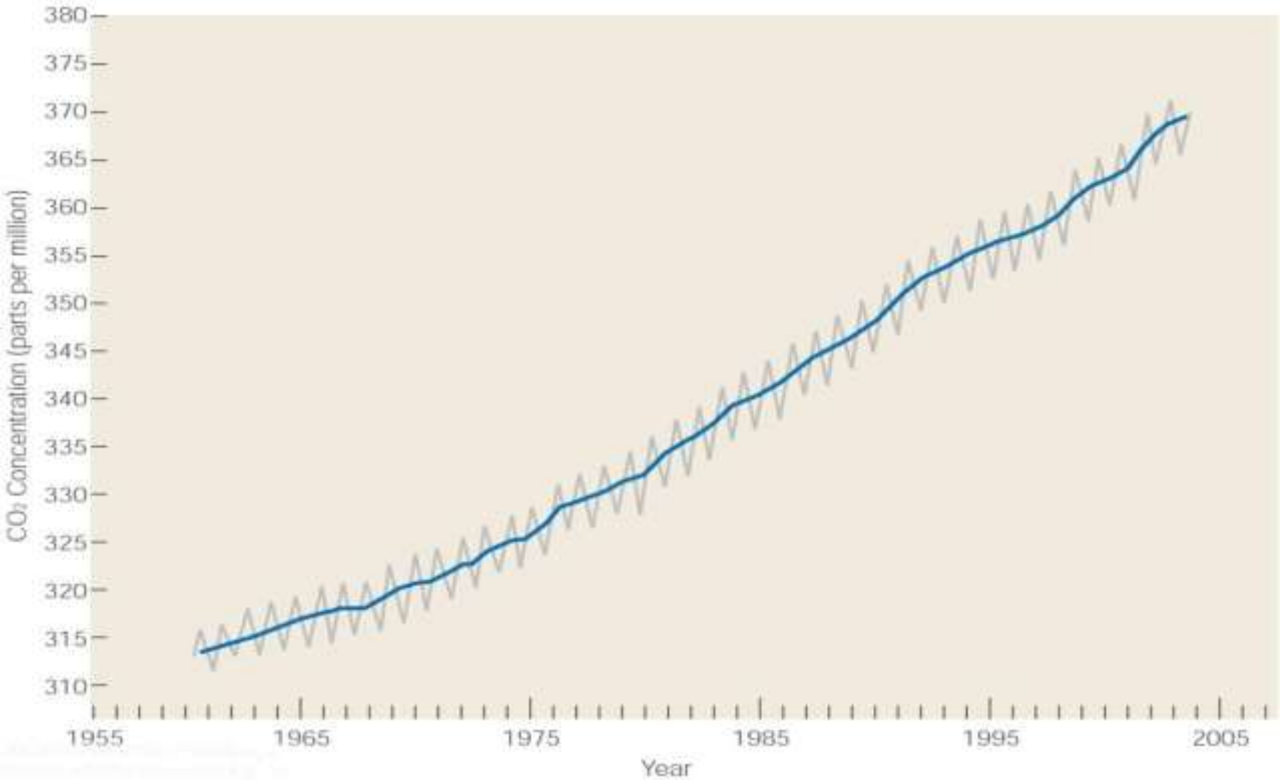
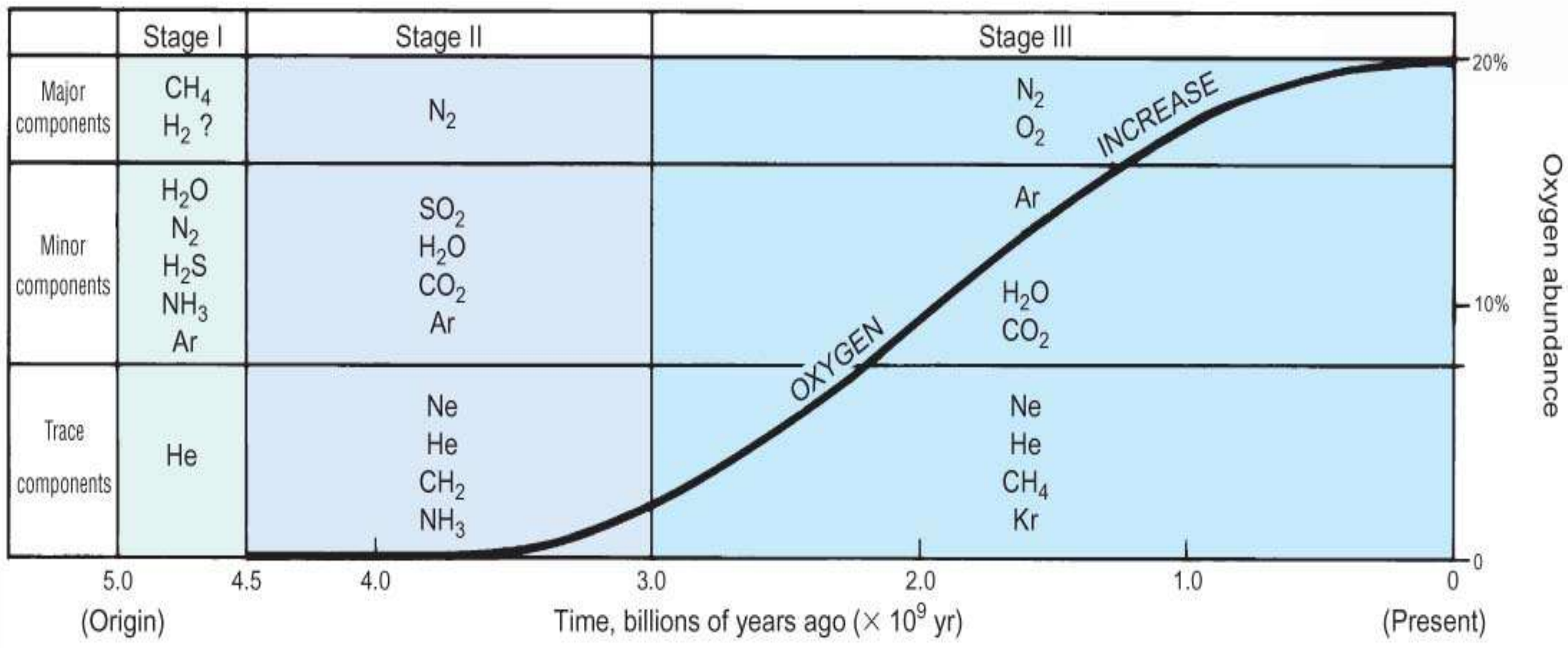


Figure 1.3

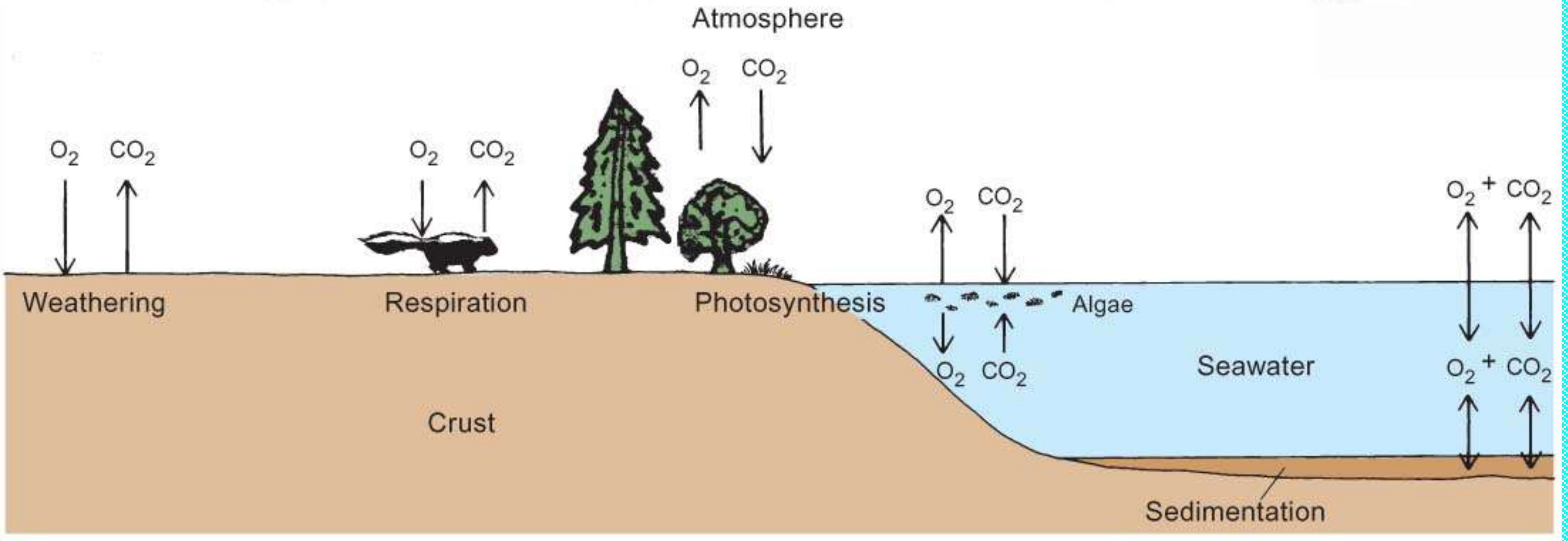
Nitrogen and oxygen concentrations experience little change, but carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons are greenhouse gases experiencing discernable increases in concentration. CO2 has risen more than 18% since 1958. Fossil fuels are the biggest problem!



	Stage I	Stage II	Stage III
Major components	CH_4 H_2 ?	N_2	N_2 O_2
Minor components	H_2O N_2 H_2S NH_3 Ar	SO_2 H_2O CO_2 Ar	Ar H_2O CO_2
Trace components	He	Ne He CH_2 NH_3	Ne He CH_4 Kr

Evolution of Earth's atmosphere from early Hadean (5 Bya) to present. Note the changes from Stage I to Stage II, particularly the evolution of nitrogen, (N) the virtual disappearance of hydrogen (H) and methane (CH_4).

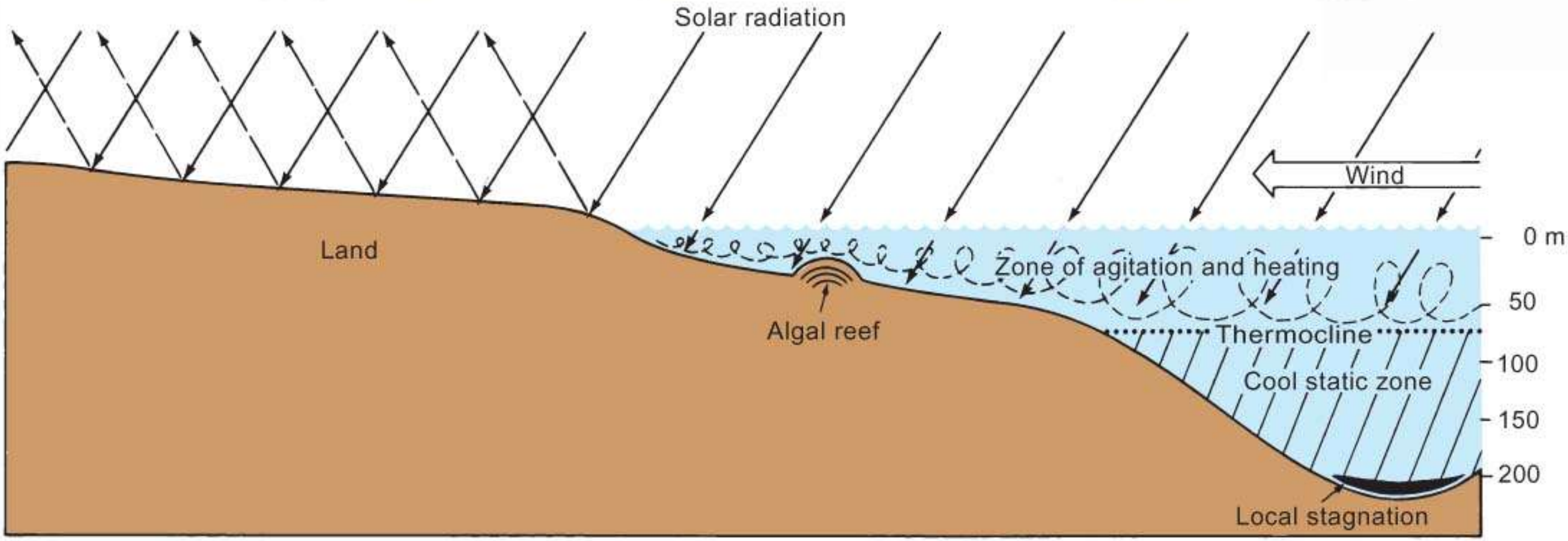
The important change from Stage II to Stage III was the rise in oxygen (due to evolution of photosynthetic algae). Note the presence of the noble gases, Ar, Ne, He and Kr. Most likely from the degassing upper mantle which continues to today.



The Global Chemostat.

This diagram shows the important flows for two elements, O and C (though not reduced C). Other important elements, such as N, P, S, Na, Ca, and K follow similar cycles. (Chemostat = hold chemistry constant or change slowly).

Start analyzing the cycle with the algae (as prime movers) and follow the chain. Algae actually started the chemostat over 4 Bya. This chemostat is one of the hallmarks of a planet with advanced life forms and it probably very rare in the universe.



The global thermostat. Shallow water is heated by the sun to form the Earth's most important heat reservoir. The photic zone above the thermocline is the habitat of algae and phytoplankton which from the base of the aquatic food chain.

Below the thermocline the water is cooler and less agitated, hence less oxygenated. These waters may even become stagnant and reducing. When they do they constitute the first step in the preservation of organic matter, which eventually leads to gas and oil deposits.

Atmospheric Greenhouse Effect

- The warming of the atmosphere by its absorbing and emitting infrared radiation while allowing shortwave radiation to pass through. The gases mainly responsible for the earth's atmospheric greenhouse effect are water vapor and carbon dioxide.

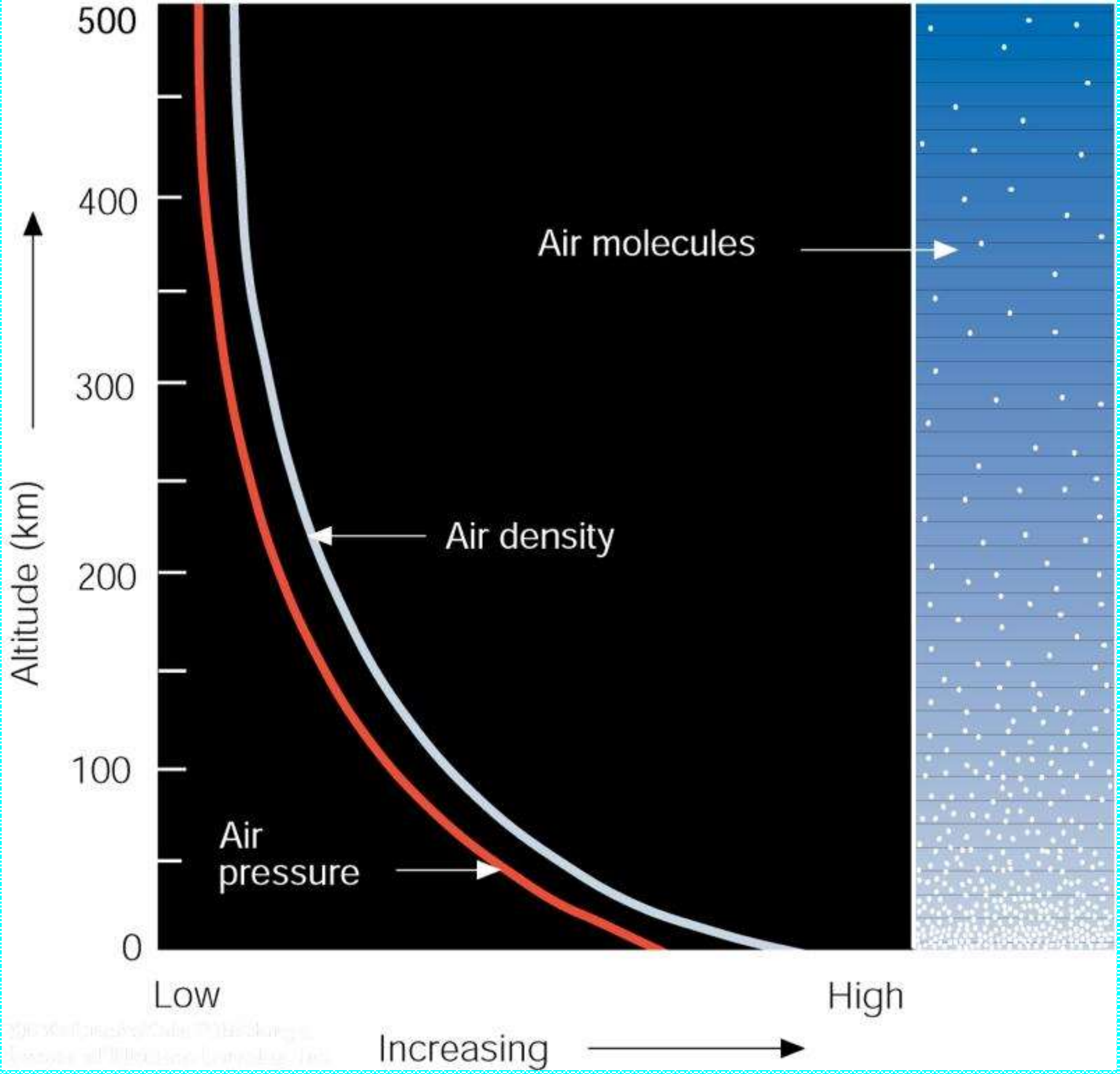
Aerosols & Pollutants

Human and natural activities displace tiny soil, salt, and ash particles as suspended aerosols,

as well as sulfur and nitrogen oxides, and hydrocarbons as pollutants.

Figure 1.6

Pressure & Density



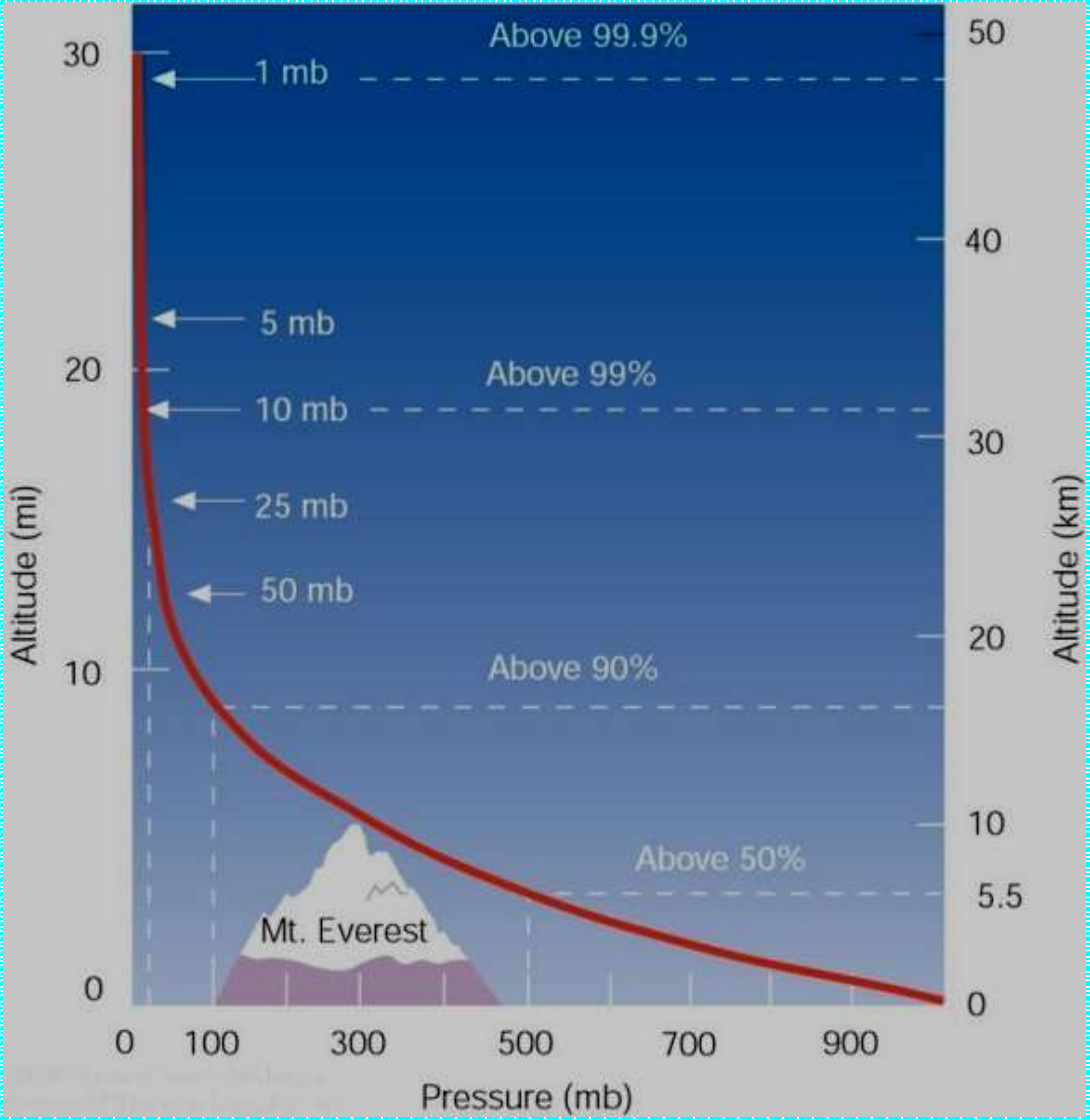
Gravity pulls gases toward earth's surface, and the whole column of gases weighs 14.7 psi at sea level, a pressure of 1013.25 mb or 29.92 in.Hg.

The amount of force exerted Over an area of surface is called
Air pressure!

Air Density is
The number of air
Molecules in a given
Space (volume)

Vertical Pressure Profile

Atmospheric pressure decreases rapidly with height. Climbing to an altitude of only 5.5 km where the pressure is 500 mb, would put you above one-half of the atmosphere's molecules.



Lapse Rate

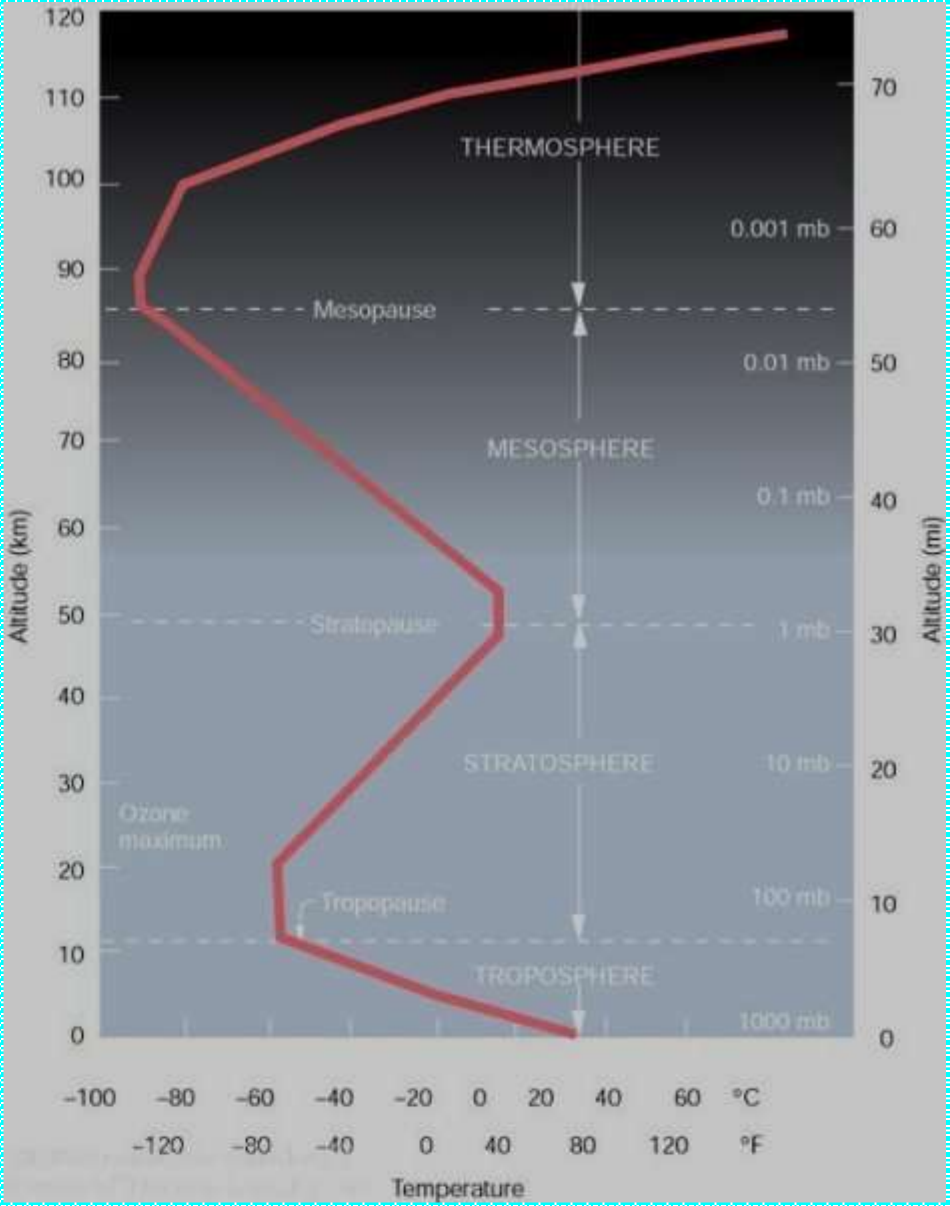
- **The rate at which air temperature decreases with height.**
- **The standard (average) lapse rate in the lower atmosphere is about 6.5°C per 1 km or 3.6°F per 1000 ft.**

Temperature Inversion

- **An increase in air temperature with height often called simply an inversion.**

- **Radiosonde – an instrument that measures the vertical profile of air temperature in the atmosphere (sometimes exceeding 100,000 ft)**

Atmospheric Layers



8 layers are defined by constant trends in average air temperature (which changes with pressure and radiation), where the outer exosphere is not shown.

1. Troposphere
2. Tropopause
3. Stratosphere
4. Stratopause
5. Mesosphere
6. Mesopause
7. Thermosphere
8. Exosphere

Atmospheric Layers

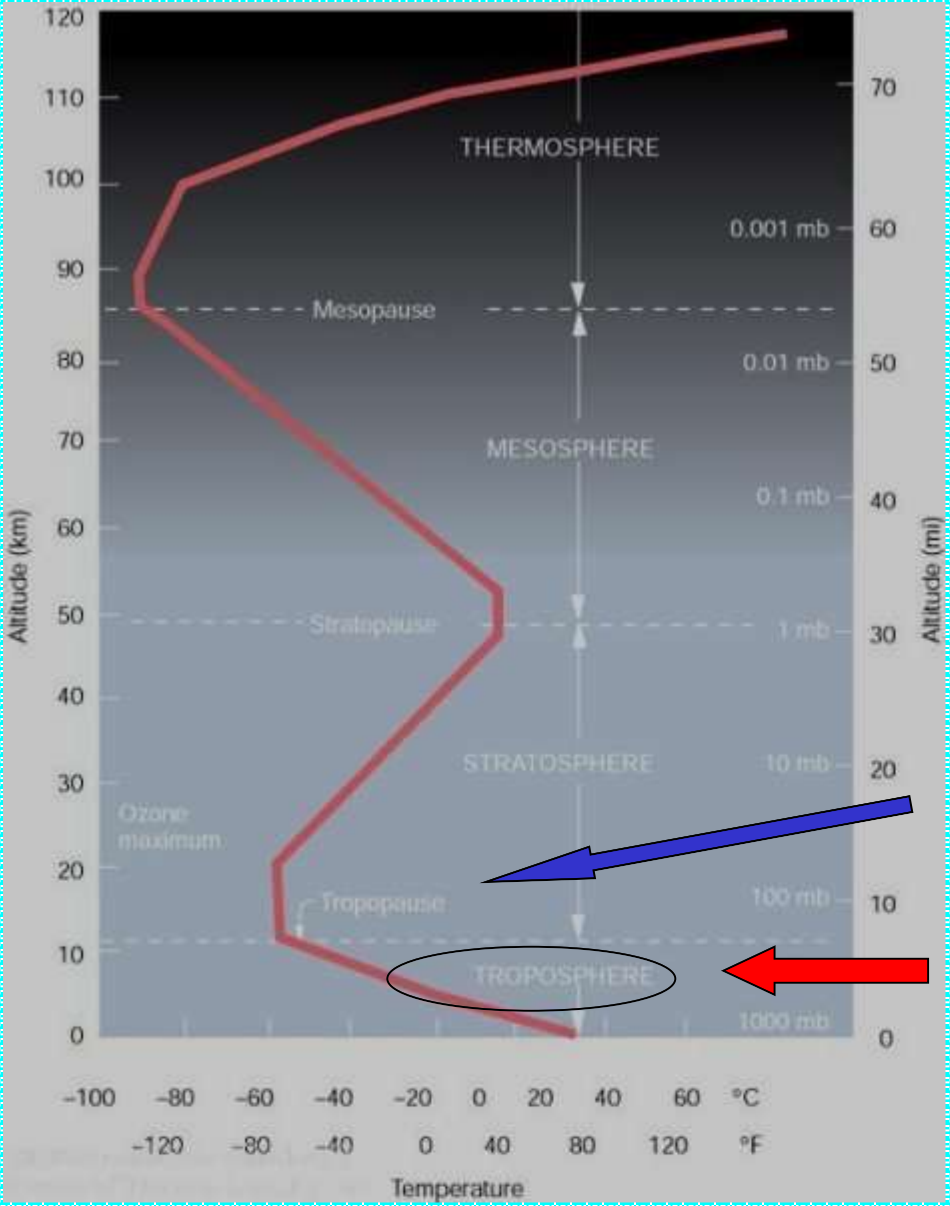
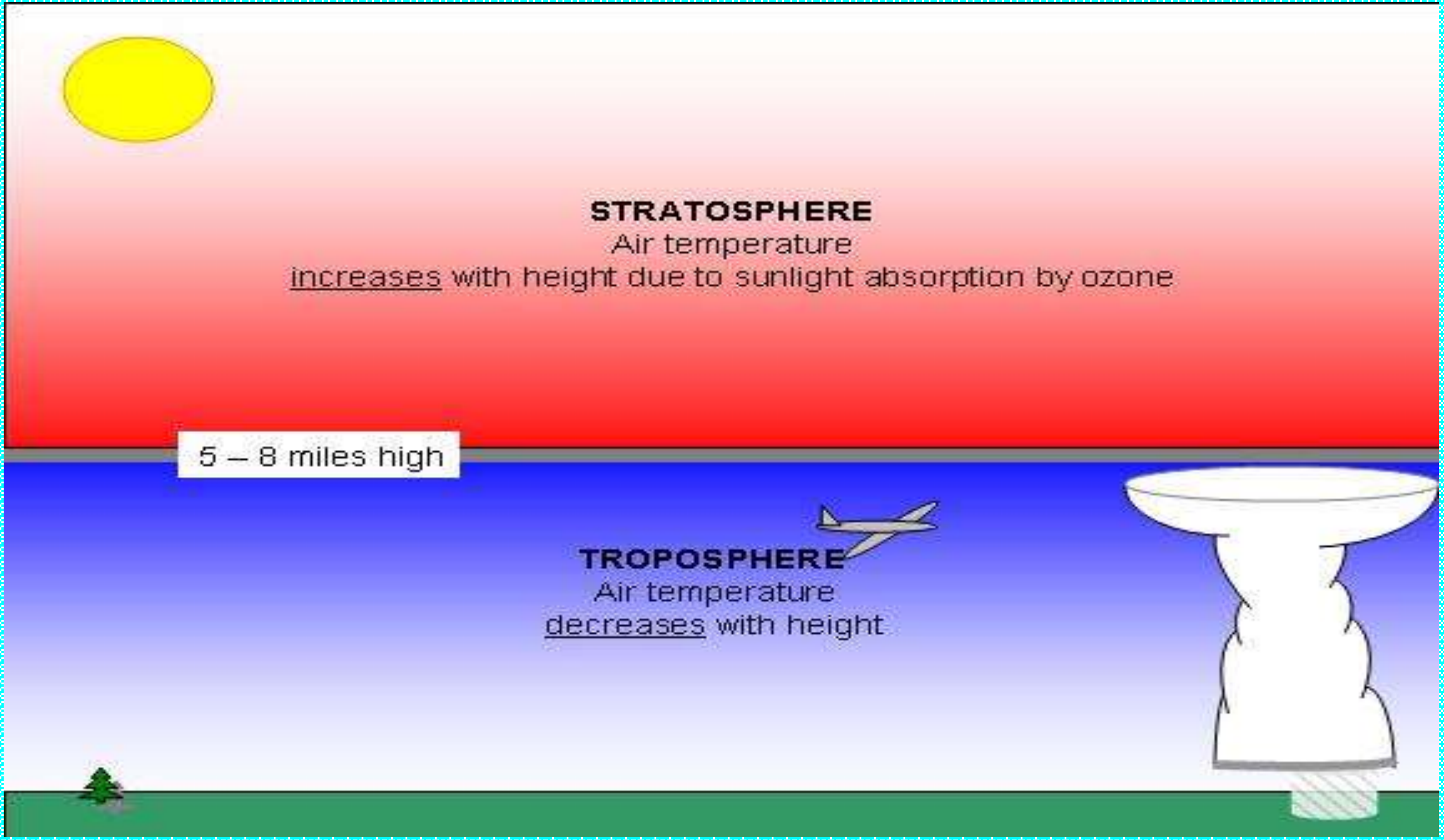


Figure 1.7

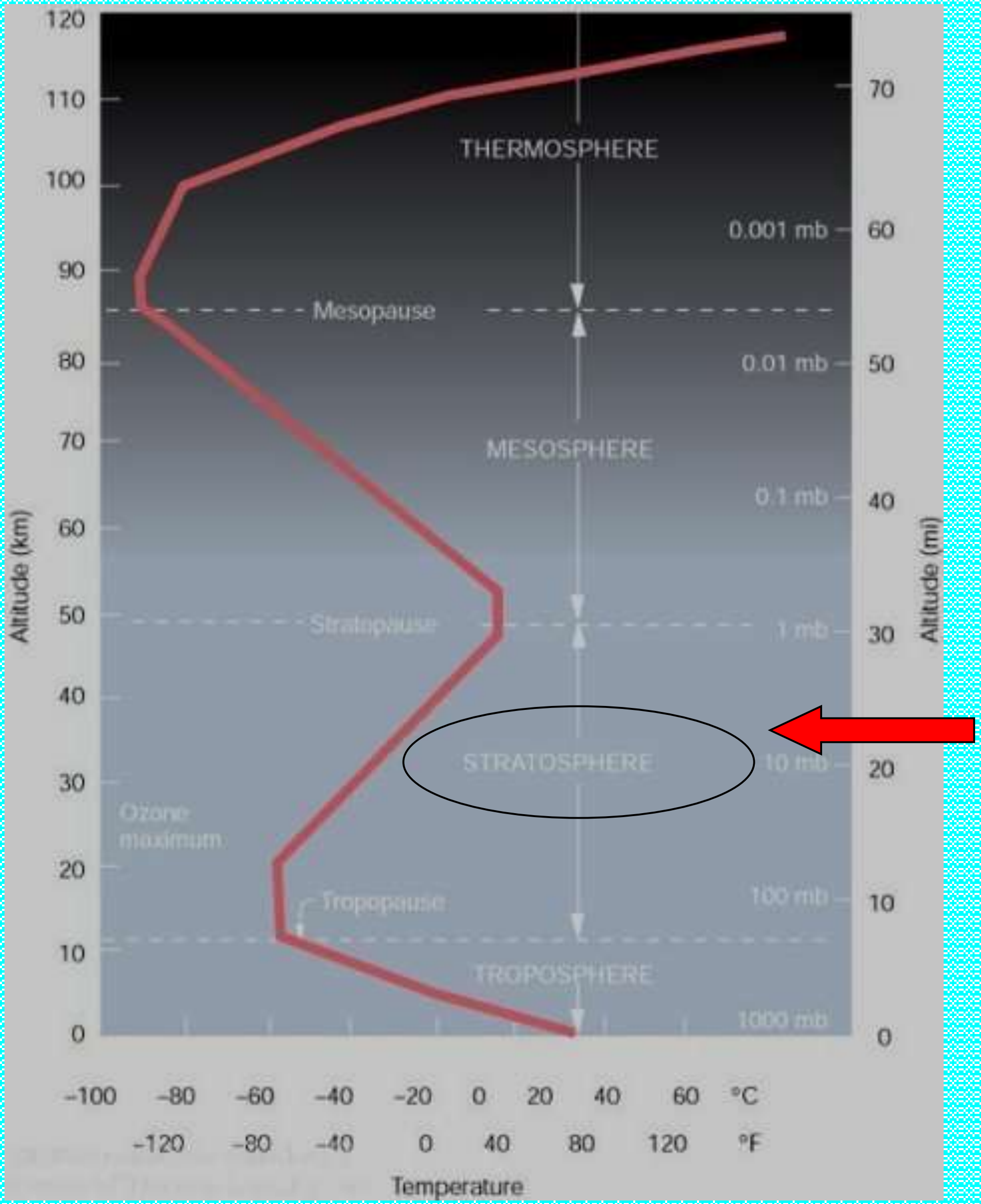
Tropopause separates Troposphere from Stratosphere. Generally higher in summer Lower in winter.

Troposphere – Temp decrease w/ height
Most of our weather occurs in this layer
Varies in height around the globe, but
Averages about 11 km in height.



The troposphere is the lowest major atmospheric layer, and is located from the Earth's surface up to the bottom of the **stratosphere**. It has decreasing temperature with height (at an average rate of 3.5° F per thousand feet (6.5 ° C per kilometer); whereas the stratosphere has either constant or slowly increasing temperature with height. The troposphere is where all of Earth's weather occurs. The boundary that divides the troposphere from the stratosphere is called the "tropopause", located at an altitude of around 5 miles in the winter, to around 8 miles high in the summer, and as high as 11 or 12 miles in the deep tropics. When you see the top of a thunderstorm flatten out into an **anvil cloud**, like in the illustration above, it is usually because the updrafts in the storm are "bumping up against" the bottom of the stratosphere

Atmospheric Layers



Stratosphere

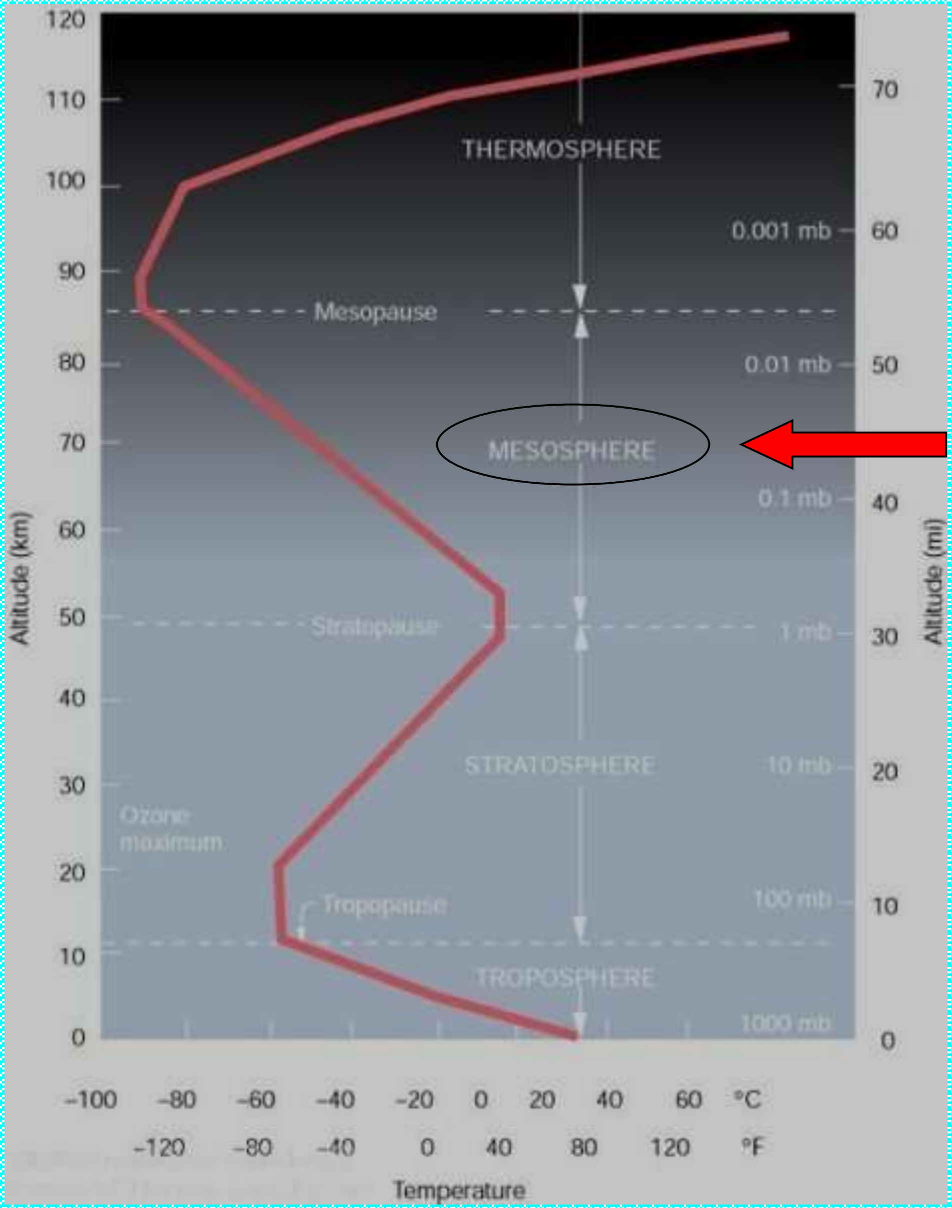
Temperature inversion in stratosphere

Ozone plays a major part in heating the air

At this altitude

Figure 1.7

Atmospheric Layers

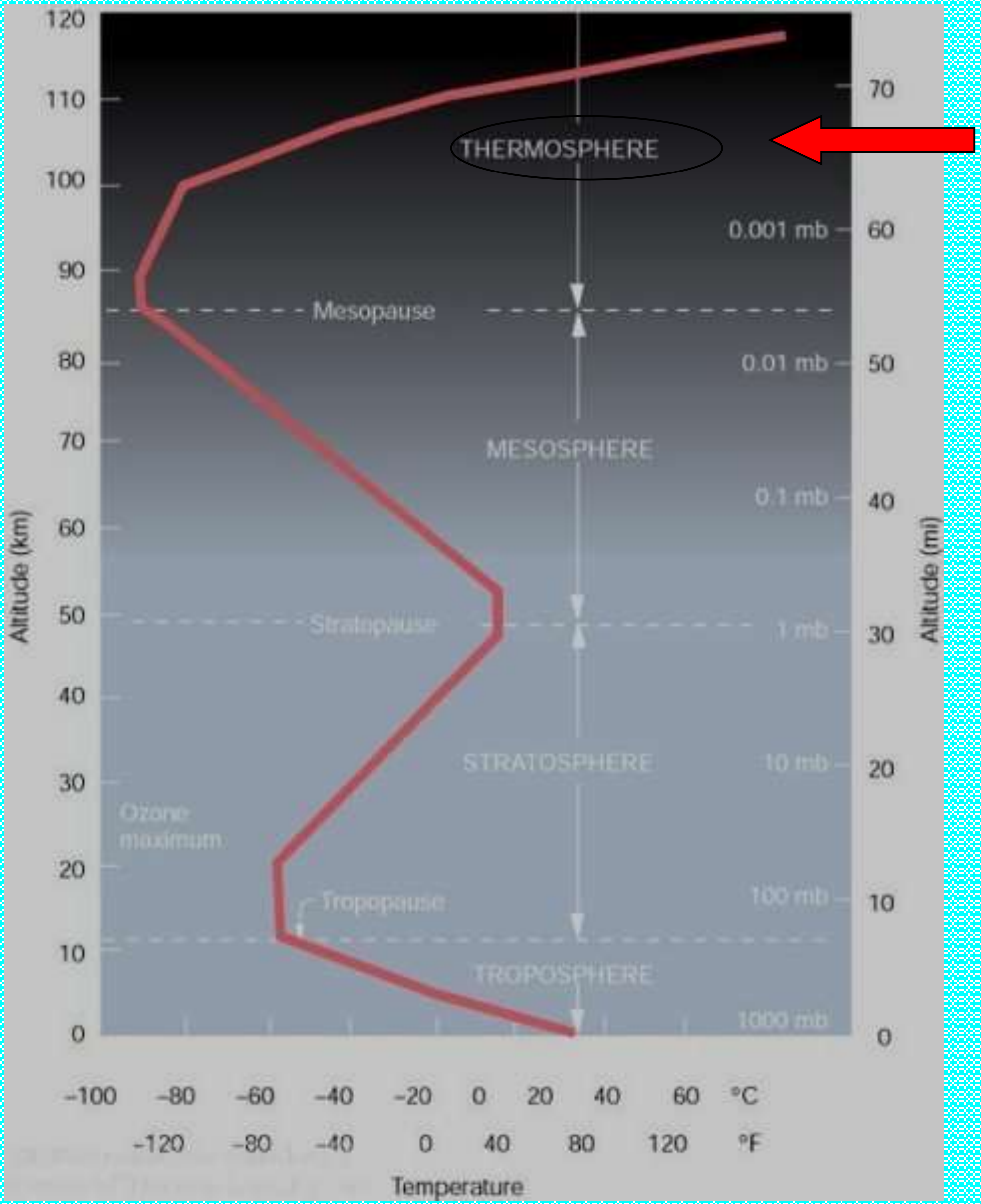


Mesosphere

Middle atmosphere – Air thin, pressure low, Need oxygen to live in this region. Air quite Cold -90°C (-130°F) near the top of mesosphere

Figure 1.7

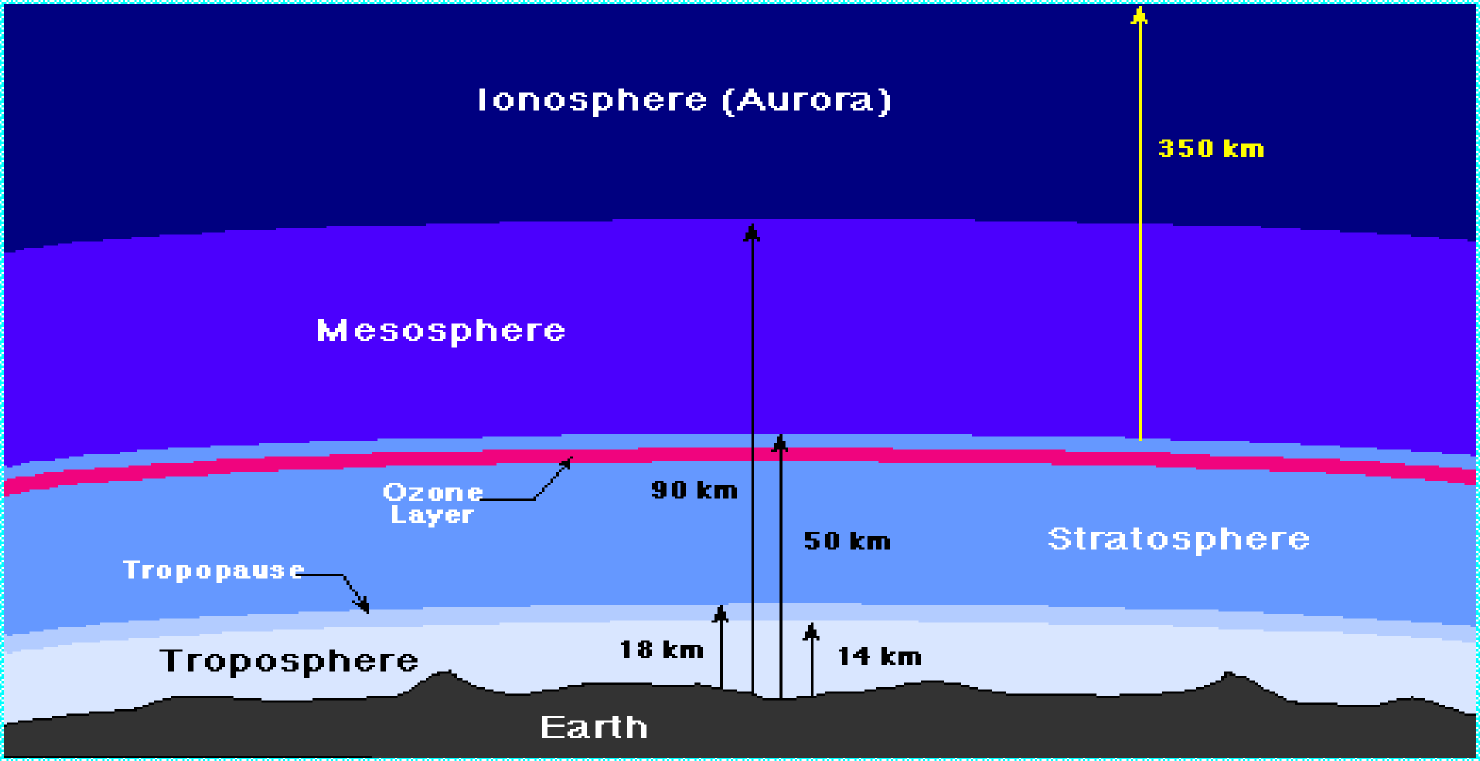
Atmospheric Layers



Thermosphere

"Hot layer" – oxygen molecules absorb energy from solar Rays warming the air. Very few atoms and molecules in this Region.

Figure 1.7



The Stratosphere and Ozone Layer

Above the troposphere is the *stratosphere*, where air flow is mostly horizontal. The thin ozone layer in the upper stratosphere has a high concentration of ozone, a particularly reactive form of oxygen. This layer is primarily responsible for absorbing the ultraviolet radiation from the Sun. The formation of this layer is a delicate matter, since only when oxygen is produced in the atmosphere can an ozone layer form and prevent an intense flux of ultraviolet radiation from reaching the surface, where it is quite hazardous to the evolution of life. There is considerable recent concern that manmade flourocarbon compounds may be depleting the ozone layer, with dire future consequences for life on the Earth.

The Mesosphere and Ionosphere

Above the stratosphere is the mesosphere and above that is the ionosphere (or *thermosphere*), where many atoms are ionized (have gained or lost electrons so they have a net electrical charge). The ionosphere is very thin, but it is where aurora take place, and is also responsible for absorbing the most energetic photons from the Sun, and for reflecting radio waves, thereby making long-distance radio communication possible.

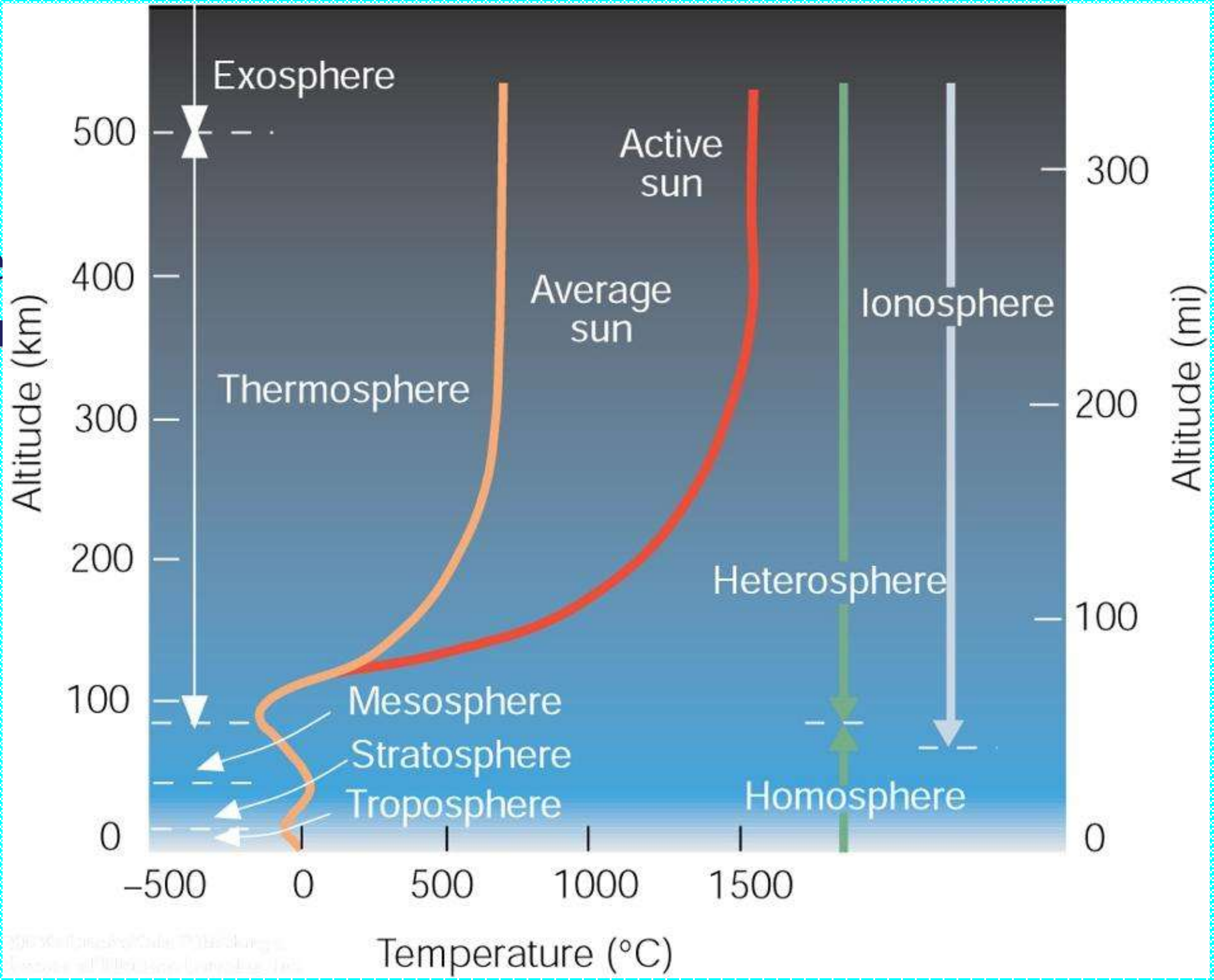
Atmospheric Mixture & Charge

Additional layers include:

a) the homosphere with 78% nitrogen and 21% oxygen

b) the poorly mixed heterosphere

c) the electrically charged ionosphere



Radio Wave Propagation

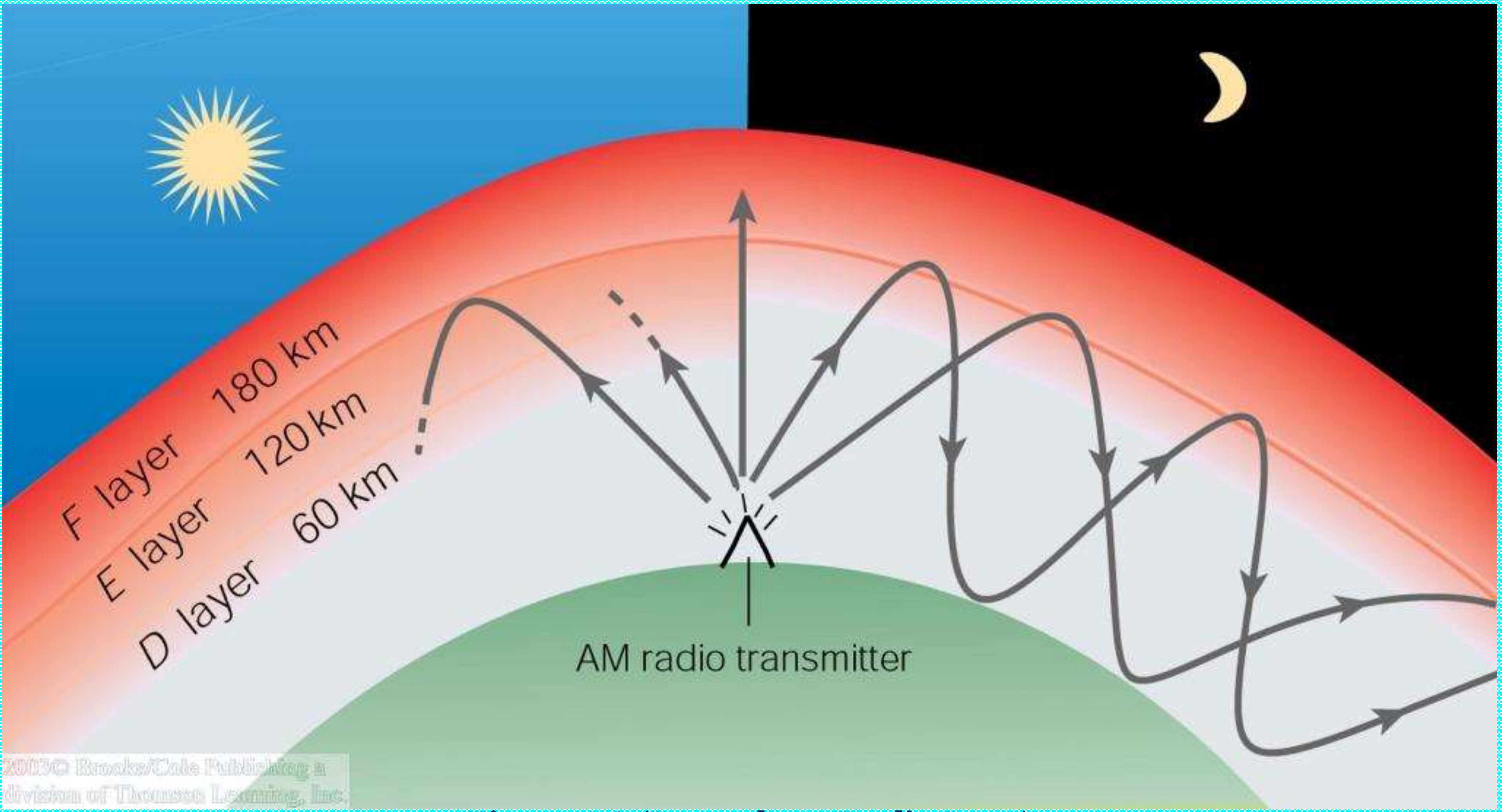


Figure 1.9 (Ionosphere Radio Prop)

AM radio waves are long enough to interfere with ions in the sun-charged D layer, but at night the D layer is weak and the AM signal propagates further, requiring stations to use less power.

Weather & Climate

Weather is comprised of the elements of:

a) air temperature
b) air pressure
c) humidity
d) clouds
e) precipitation
f) visibility
g) wind

Climate represents long-term (e.g. 30 yr) averages of weather.

Impacts of Weather 3/5

Figure 1.14

Impacts of Weather 5/5

Figure 1.16

Lightning strikes earth 100 times every second

- Most climatic variations are due to the uneven heating of Earth's surface
  - This is a result of the variation in solar radiation at different latitudes

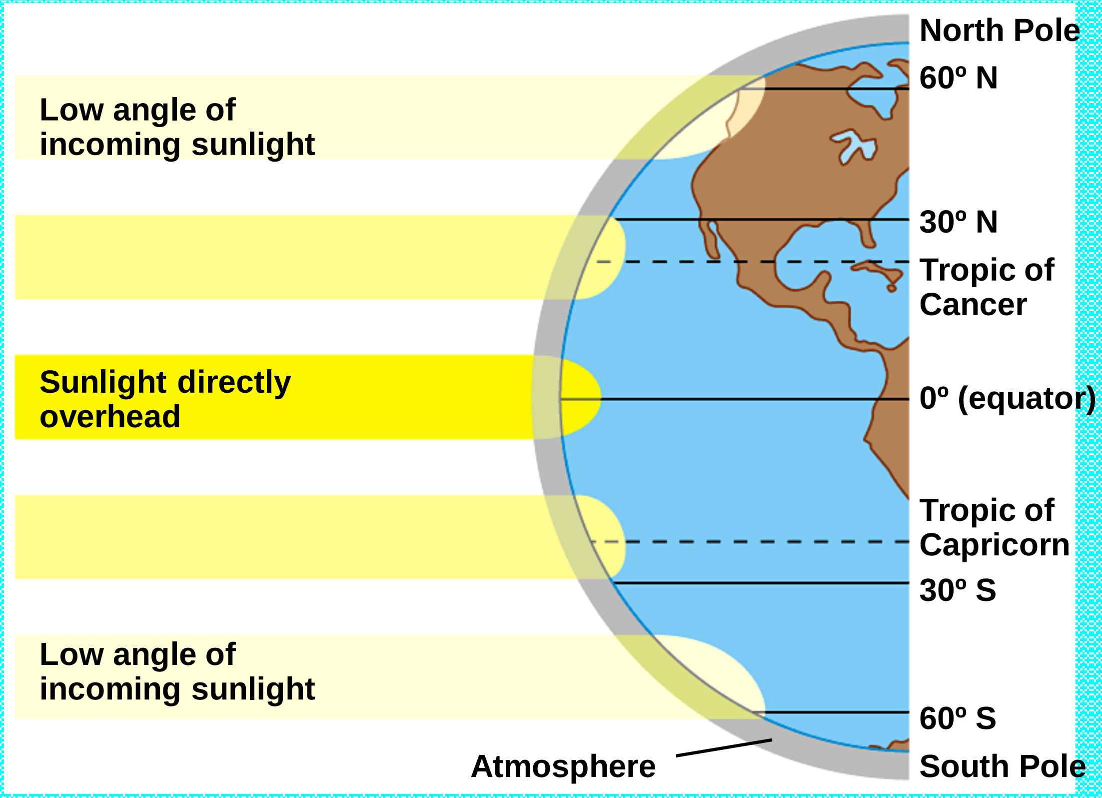


Figure 34.6A

- The seasons of the year result from the permanent tilt of the planet on its axis as it orbits the sun

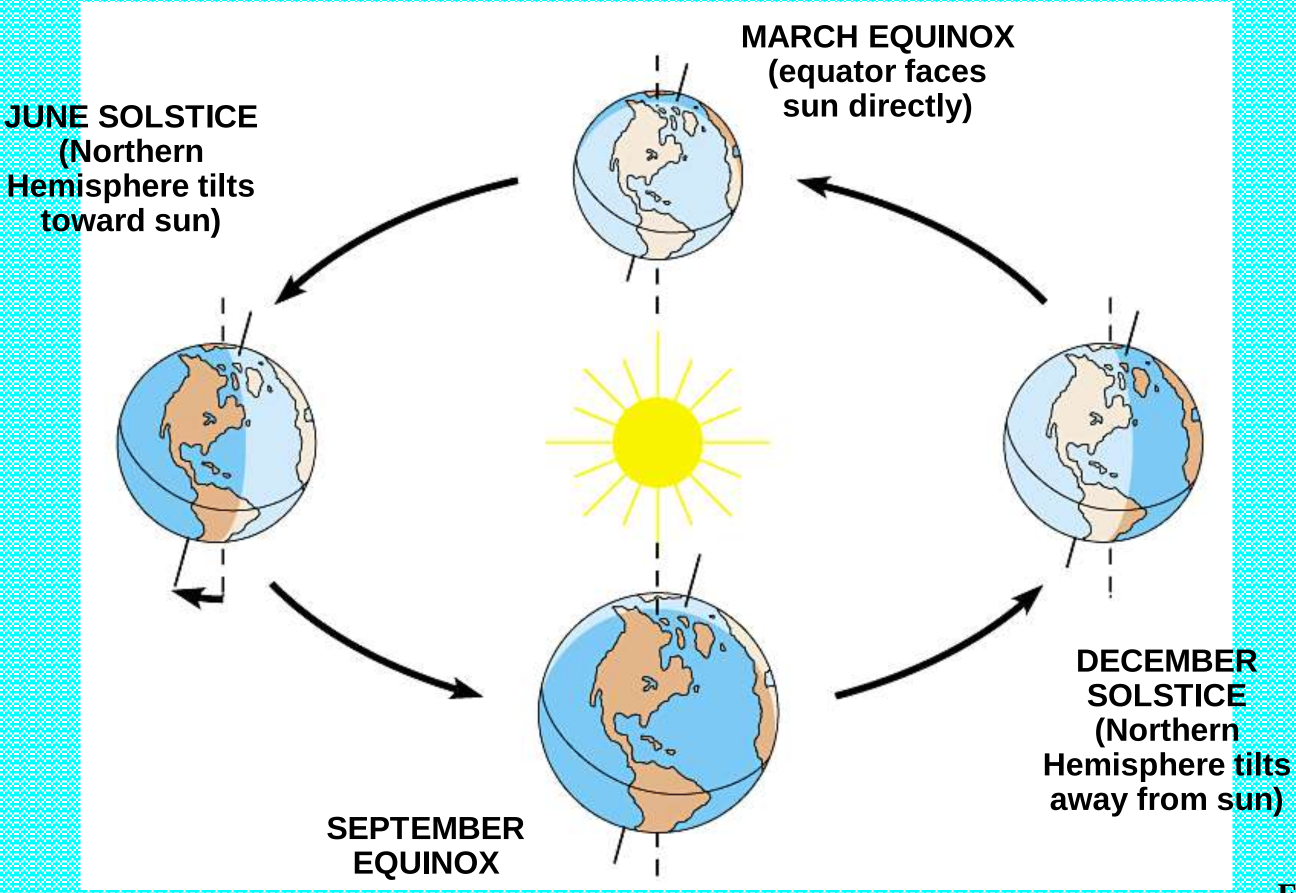
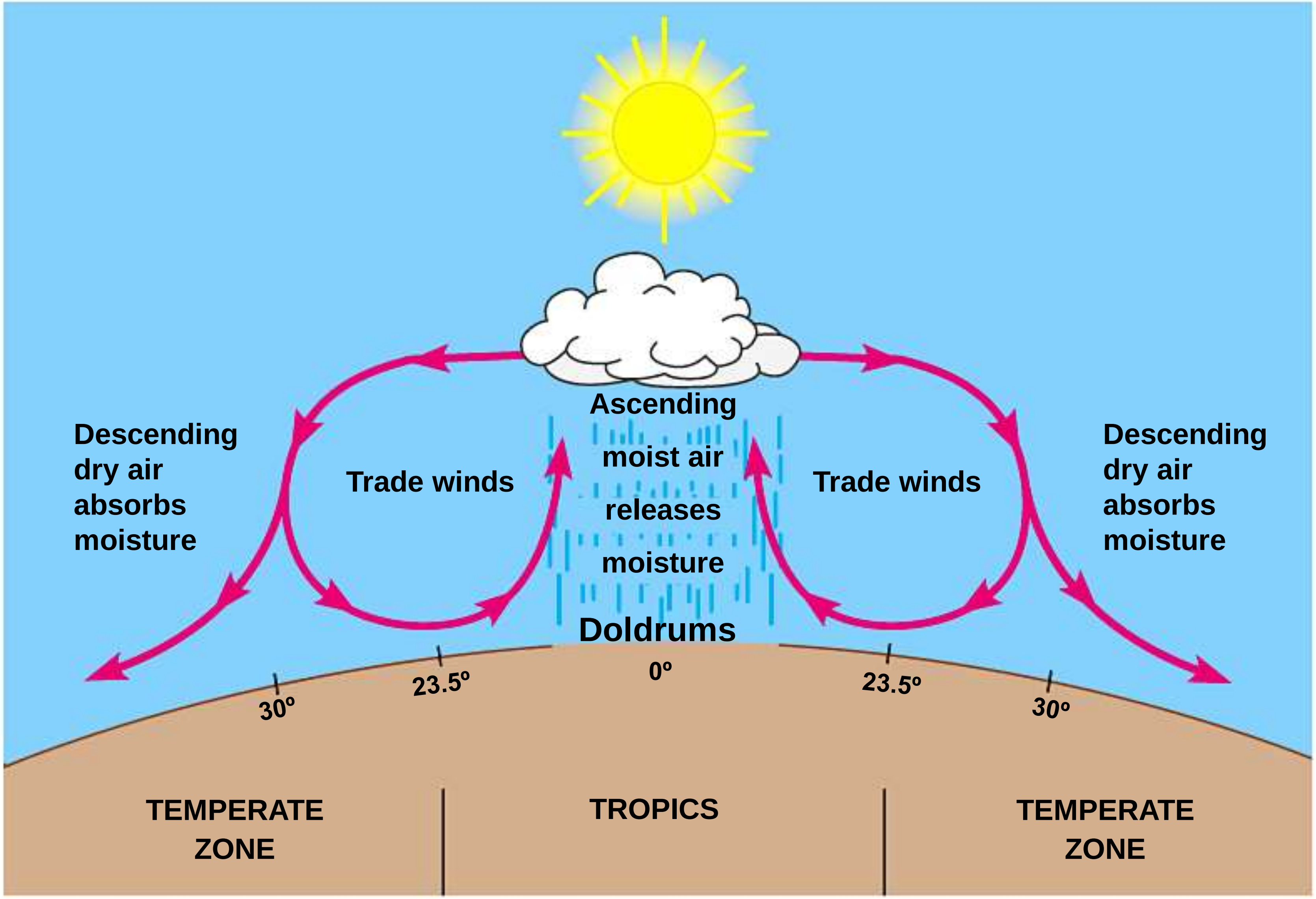


Figure 34.6B

- The tropics experience the greatest annual input and least seasonal variation in solar radiation

- **The direct intense solar radiation near the equator has an impact on the global patterns of rainfall and winds**



Descending dry air absorbs moisture

Trade winds

Ascending moist air releases moisture

Doldrums

Trade winds

Descending dry air absorbs moisture

30°

23.5°

0°

23.5°

30°

TEMPERATE ZONE

TROPICS

TEMPERATE ZONE

Figure 34.6C

- Warm, moist air at the equator rises
- **As the air rises, it cools and releases much of its water content**
  - **This results in the abundant precipitation typical of most tropical regions**
- **After losing their moisture over equatorial zones, high altitude air masses spread away from the equator**

- They cool and descend again at latitudes of about 30° north and south
  - **This explains the locations of the world's great deserts**
- **As the dry air descends, some of it spreads back toward the equator**
  - **This creates the cooling trade winds that dominate the tropics**

- Temperate zones are located between the tropics and the Arctic Circle in the north and the Antarctic Circle in the south
  - **They have seasonal variations in climate**
  - **The temperatures are more moderate than in the tropic or polar regions**

- Prevailing winds result from the combined effects of the rising and falling of air masses and Earth's rotation
  - **In the tropics, Earth's rapidly moving surface deflects vertically circulating air, making the winds blow from east to west**
  - **In temperate zones, the slower-moving surface produces the westerlies winds that blow from west to east**

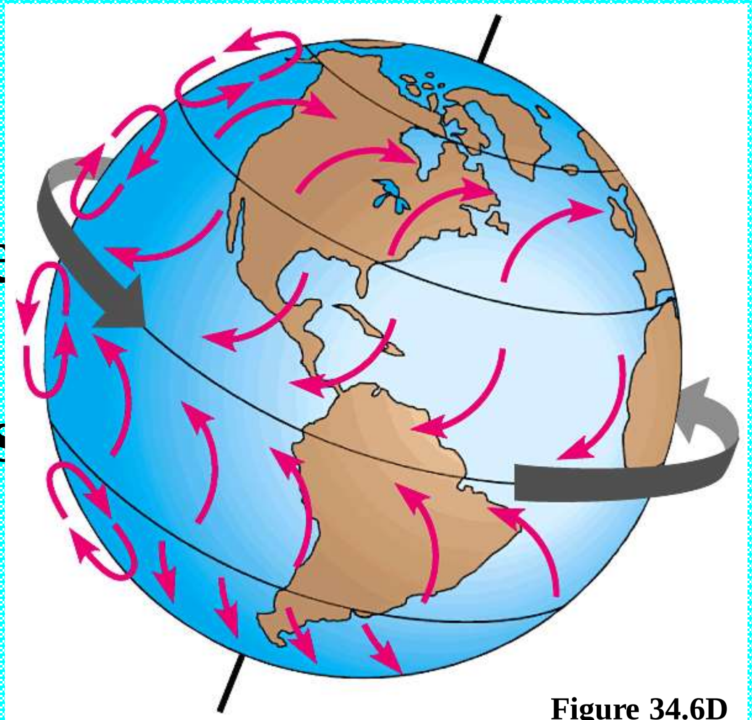
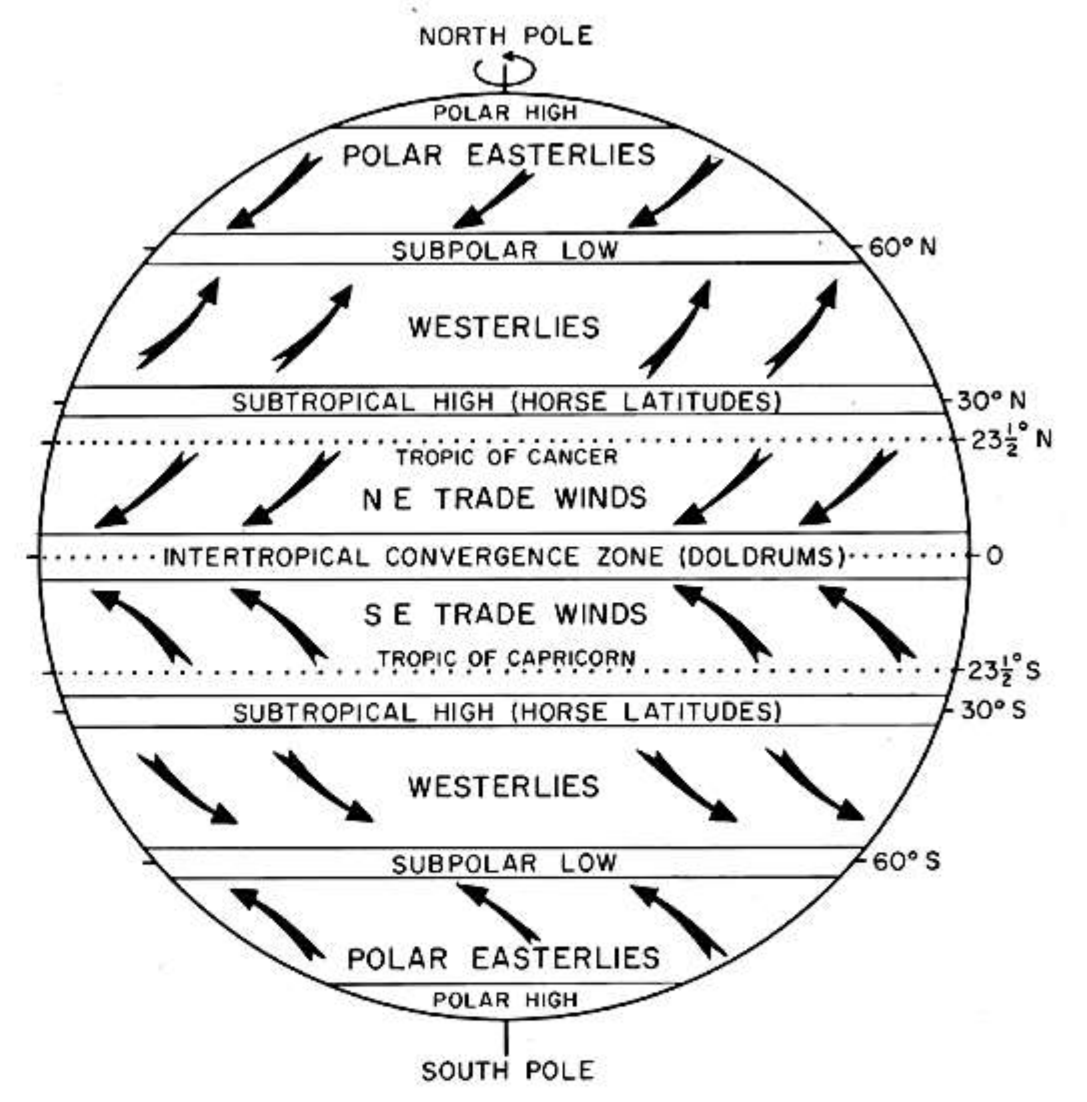


Figure 34.6D

Atmospheric Circulation Patterns

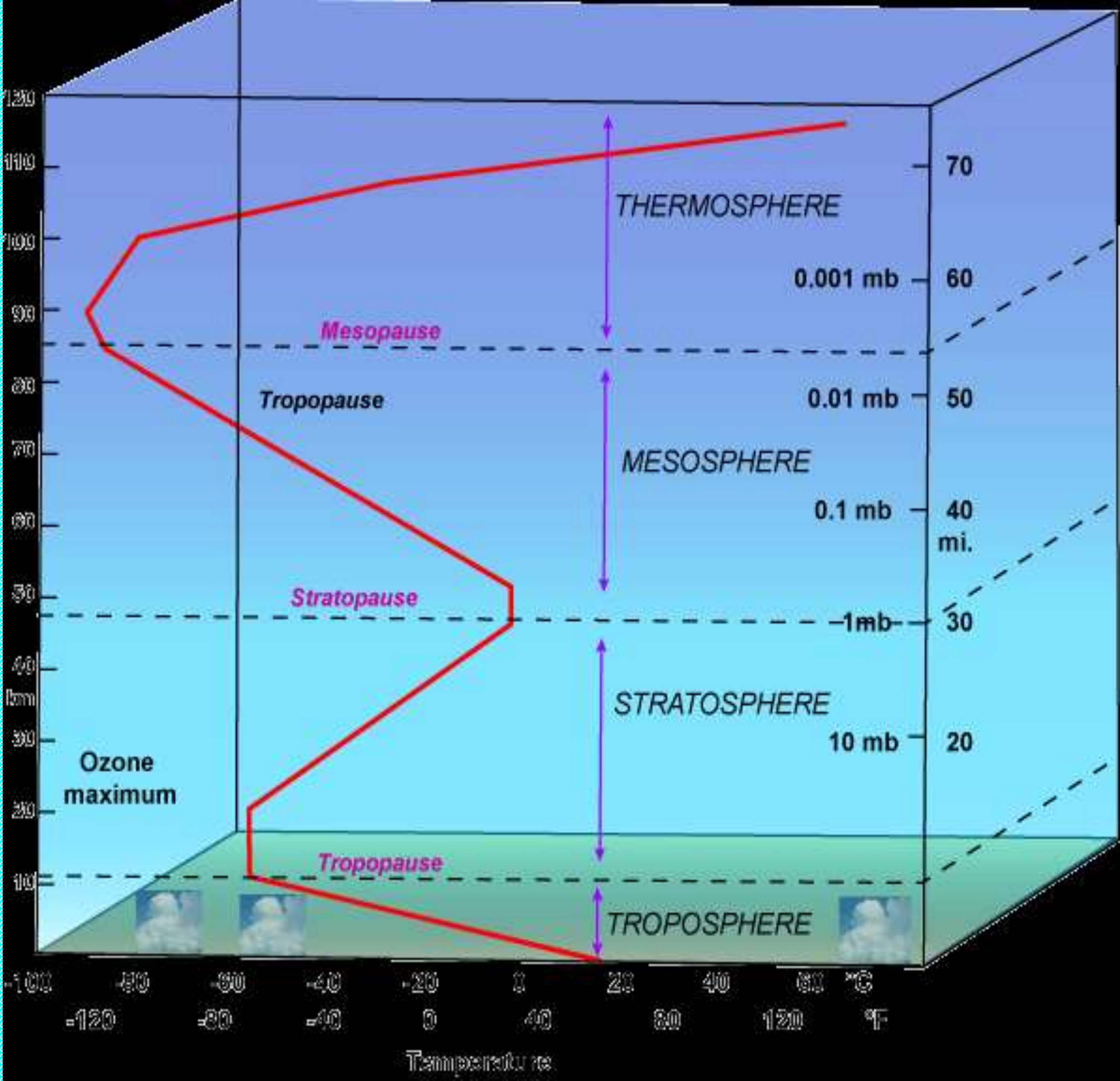


Lapse Rates and Stability of the Atmosphere

What is a lapse rate?

- A lapse rate is defined as the rate of change in temperature observed while moving upwards through the Earth's atmosphere.

Atmospheric Temperature Profile with Height.



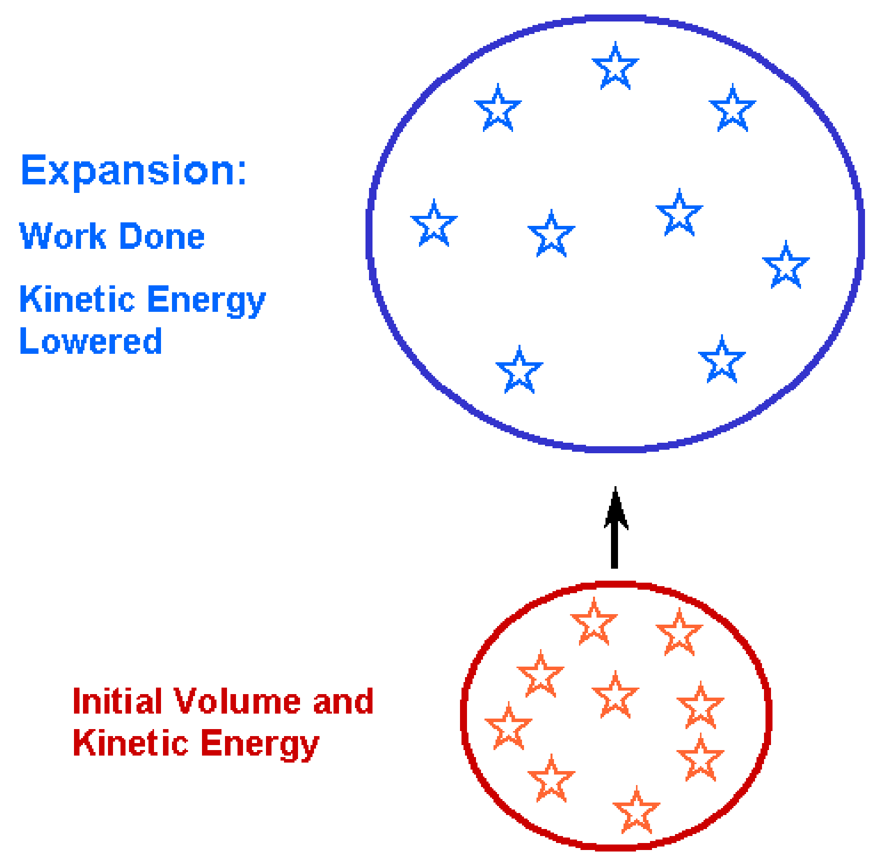
Key points

- Rate at which a temperature decreases with height.
- Units: generally C/km, sometimes K/km

Stability of Atmosphere

- One of the processes that are connected to vertical motions in the atmosphere is **stability**. This describes the tendency for the atmosphere to either **resist** or **enhance** vertical motions. The stability of the atmosphere is directly related to the changes of temperature with height.

- First we need to consider the temperature changes experienced by rising air. As a parcel of air rises it moves into regions of lowe
- r pressure. This means that the surrounding air is pushing on the parcel with less force. So the air in the parcel will expand, and the volume will become larger.



When the air expands, the molecules must now cover a larger volume. This means that the air in the parcel must perform work to inhabit the increased volume. The work done by the parcel will result in lower kinetic energy, and the temperature must fall.

Adiabats Revisited

- The rate at which rising air cools can be determined from a famous expression called the 1st law of Thermodynamics, which describes the relationship between temperature and pressure changes.
- First let us note that most rising parcels of air are large enough that the amount of mixing with the surrounding air is negligible. So there is effectively no transfer of energy between the parcel of air and the surroundings. Such a system is called **adiabatic**.
- Adiabatic = no exchange of energy with the outside environment.

1st Law of Thermodynamics

Temperature Change ~ Energy Flow In/Out + Change in Pressure

If no energy exchange with surroundings -- Adiabatic

Temperature Change ~ Pressure Change

or

Temperature Change ~ Changes in Internal energy of volume due to expansion or compression

Dry Adiabatic Lapse Rate

- The result is that rising air will cool about 10 degrees C/km (actual rate = 9.8 degrees C/km). This is called the **Dry Adiabatic Lapse Rate**.
- The word dry means the air is unsaturated. We have just defined adiabatic. Lapse rate describes a decrease in something with height. So the term can be translated into the rate of temperature decrease of rising air that is unsaturated.

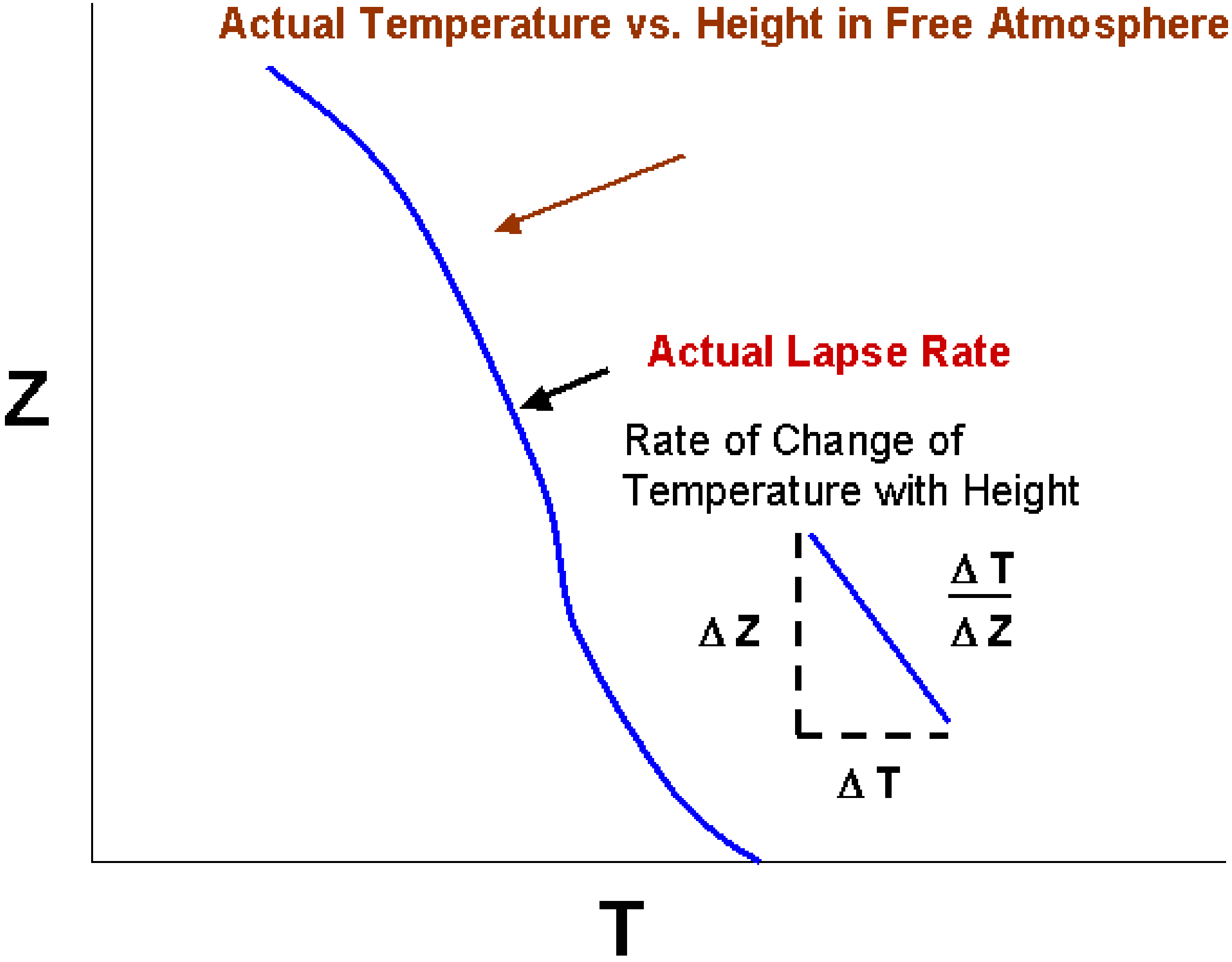
Now, what happens when air becomes saturated?

- Consider: condensation causes a release of latent heat.
- So the expansion of the air will induce a cooling, but this will be partially offset by heat release from the condensation of water.
- As a result, the rate of temperature change of rising air that is saturated is smaller than for dry air. This is called the **Moist Adiabatic Lapse Rate**, and it is not a constant value. This is because the rate of condensation changes with height.

Moist Adiabatic Lapse Rate

- Initially, the newly saturated air will have a large rate of condensation. But as the air continues to rise, and more water vapor changes to liquid, it becomes drier. The formation of water droplets by condensation accordingly reduces as the air continues to rise. T
- The moist rate varies between about 4 and 9 C/km. It is reasonable for us to assume an "average" value of about 5 or 6 C/km.

Stability of the atmosphere

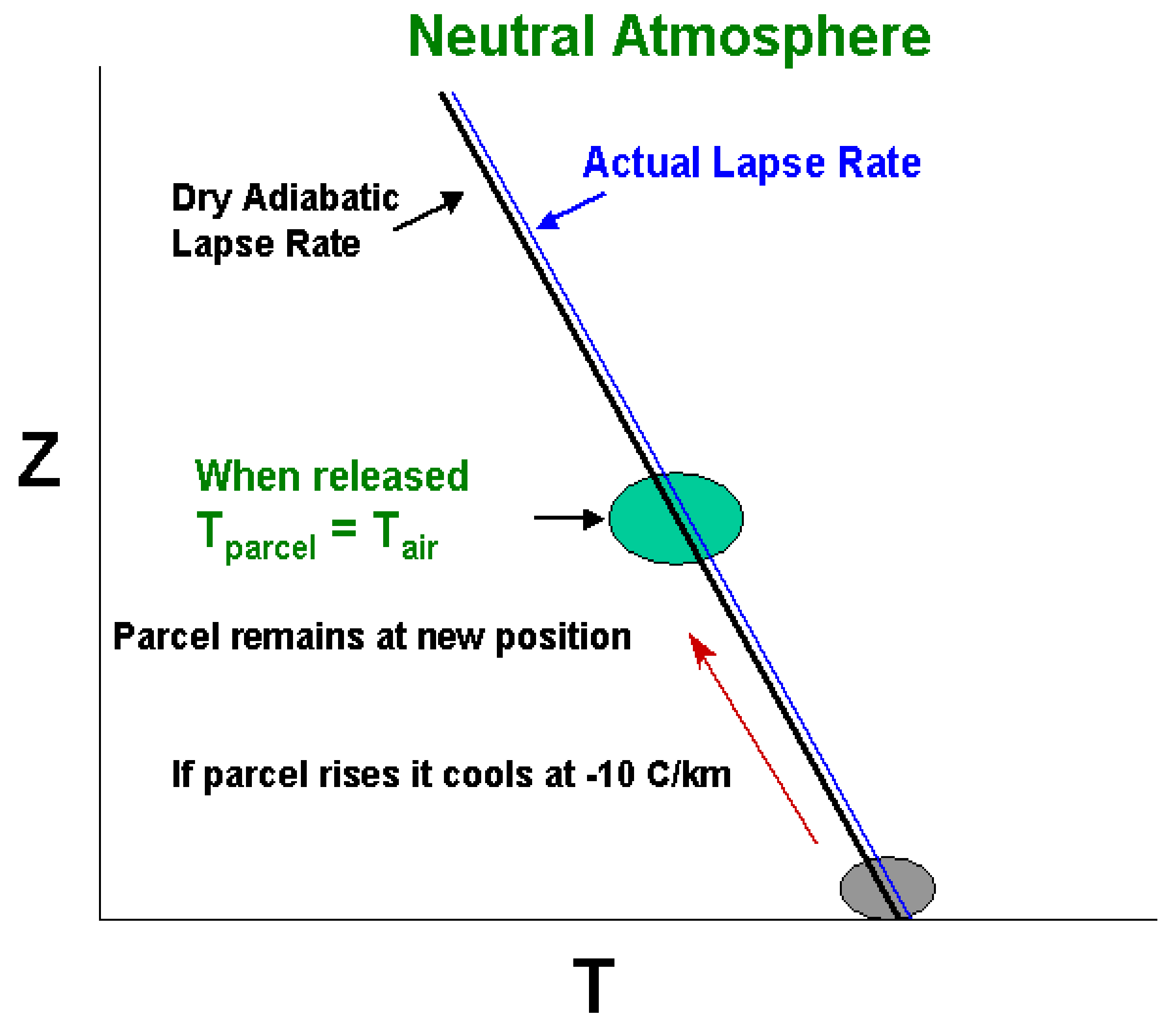


Actual Lapse Rate

Rate of Change of Temperature with Height

$$\frac{\Delta T}{\Delta Z}$$

Neutral Atmosphere

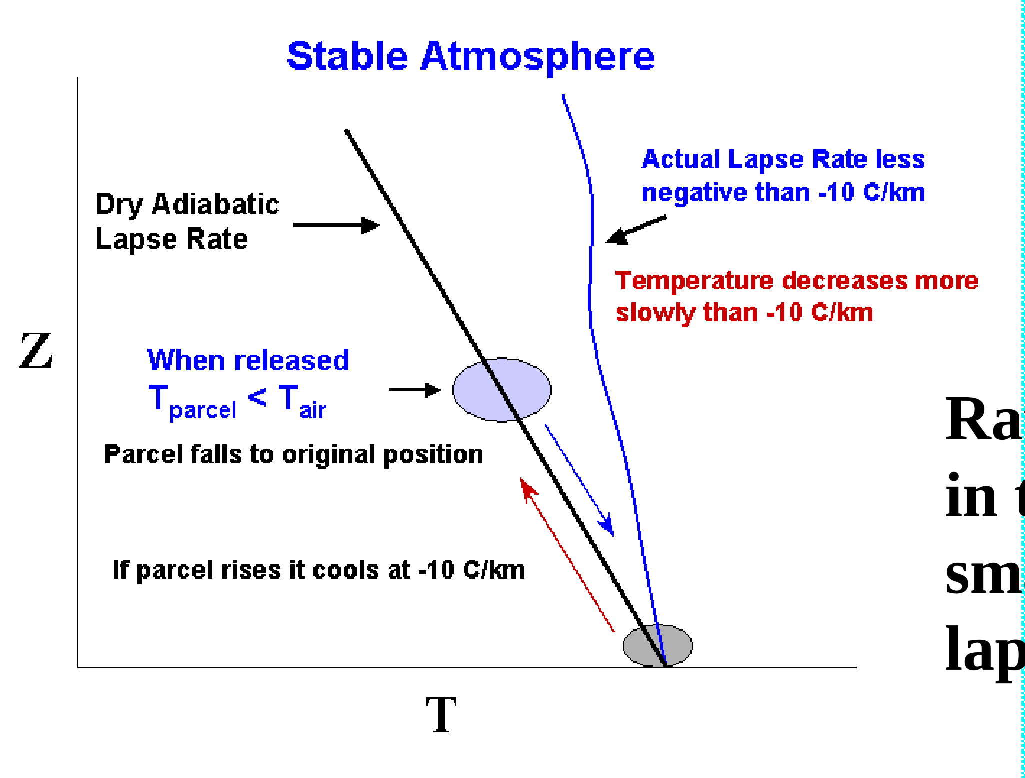


If you lifted a par in a neutral atmosphere the lapse rate equals the dry adiabati lapse rate.

Density of the ai inside the parcel density of air out the parcel.

Therefore, the pa has no buoyancy (upward motion)

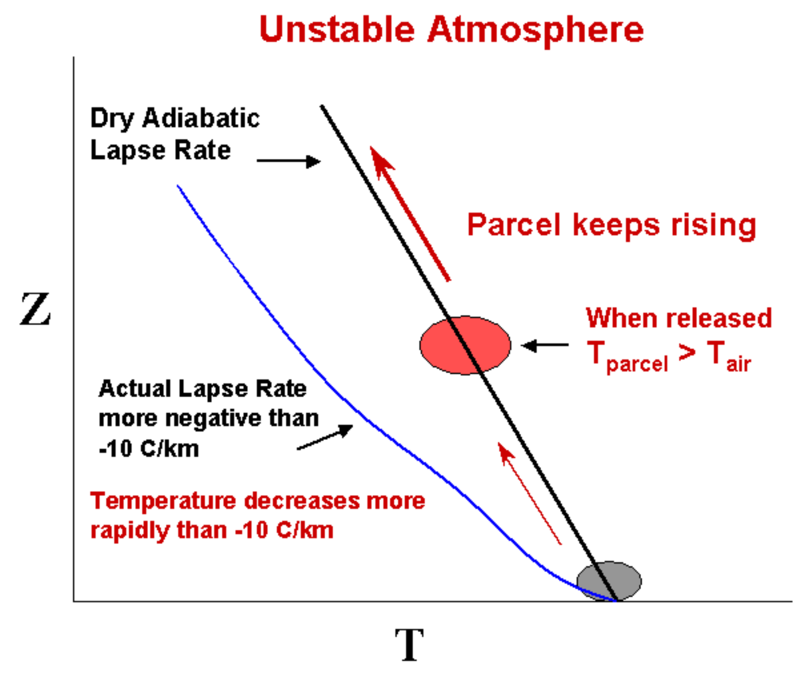
Stable Atmosphere



Rate of temperature decrease in the free atmosphere is smaller that the dry adiabatic lapse rate.

The actual lapse rate is less than a
decrease of 10 C/km. It could even be positive, and temperatures
may increase with height.

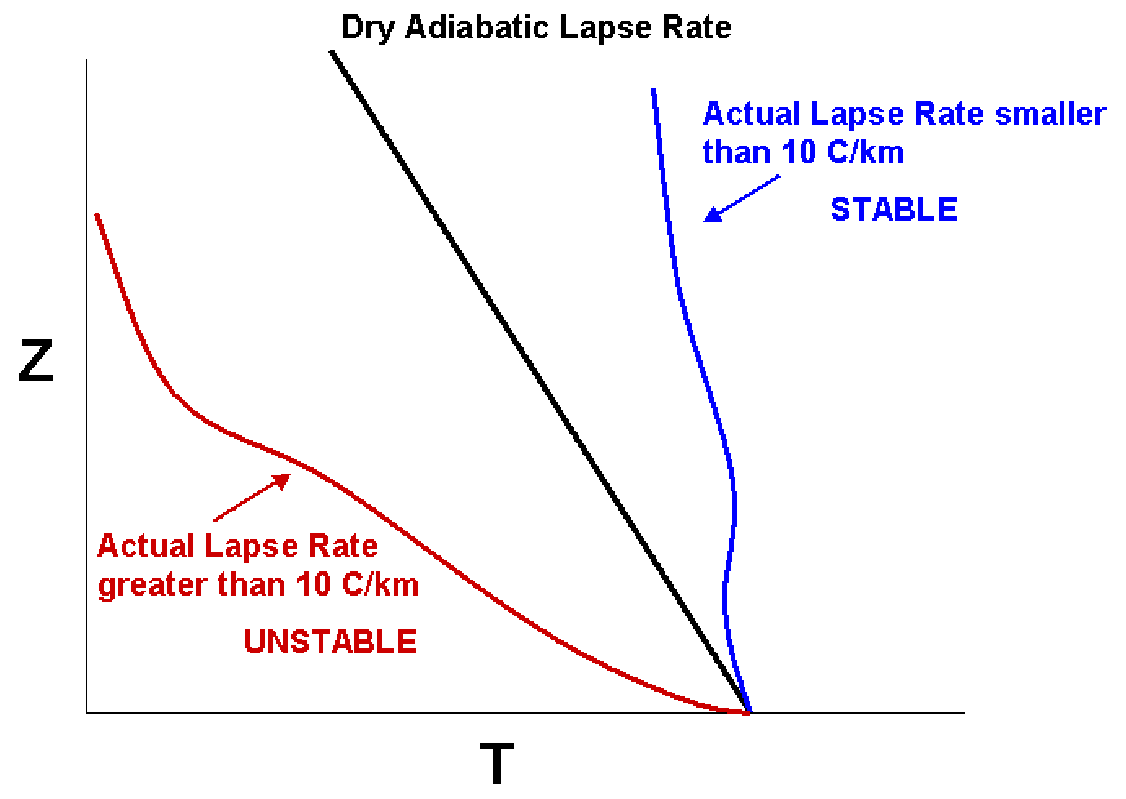
Unstable Atmosphere



Temperature decreases with height in the environment more rapidly than the dry adiabatic rate.
The actual lapse rate is more negative than –10 C/km. (Colder with height faster)When a parcel is forced to rise any distance, it becomes warmer than the surrounding air. Since it is now less dense than the environment, the parcel will keep rising.

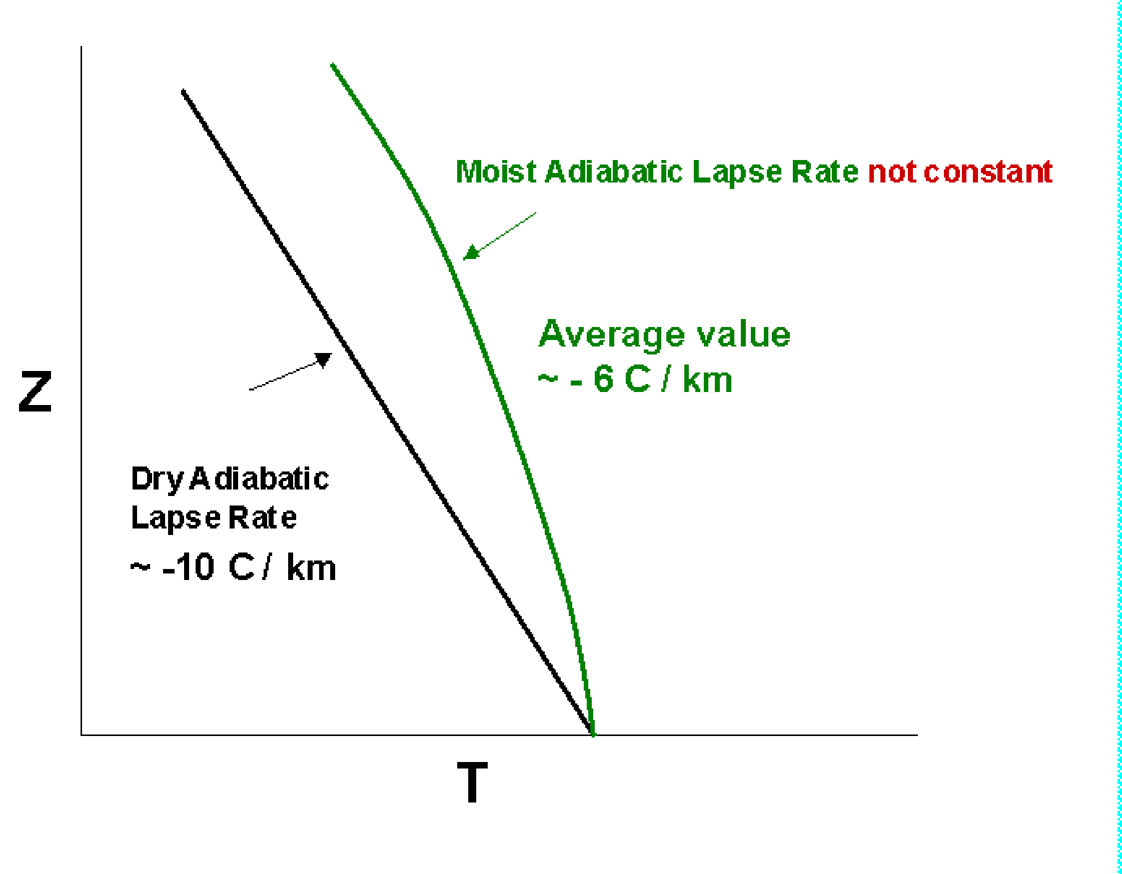
The air is unstable, and vertical motions are enhanced. Rising motions are very likely in such an atmosphere.

Classes of Stability for **unsaturated air**



For an unsaturated atmosphere, all you need to know to characterize stability of the air is the actual change of height with temperature. (Meaning the actual or environmental lapse rate.)

Stability and Saturated Air



Recall that when rising air becomes saturated, latent heat is released, and slows the rate of cooling. The moist adiabatic rate is variable, but always less negative than the dry adiabatic rate.

Important Notes: Saturated Atmosphere

- Note that the rate of cooling is initially much slower than the dry adiabatic rate, since the rate of condensation is initially large, and latent heat release is great.

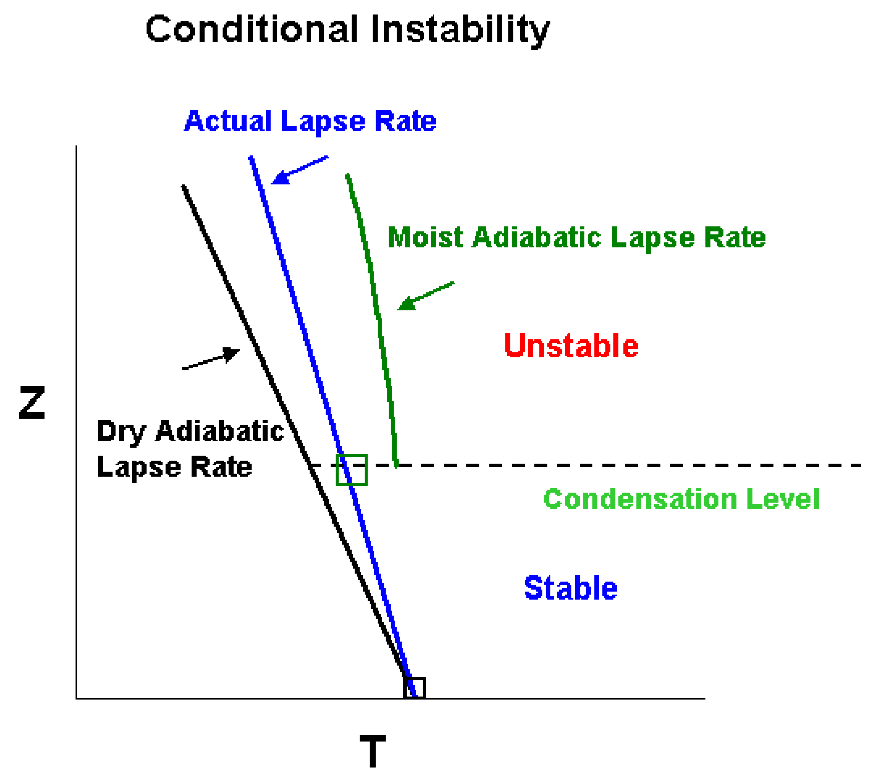
- As the air continues to rise, the water vapor concentration is reduced, since it is being changed to liquid droplets. As a result, the rate of condensation becomes smaller as the parcel rises, and the associated latent heat release is reduced. So the rate of cooling increases.

- Eventually, if the air rises far enough, the parcel becomes dry and the rate of cooling reaches the dry adiabatic rate. An average value for the moist adiabatic rate can be estimated as about –5 or –6 C/km.

Absolute Stability

- If the environmental (actual) lapse rate is less negative than the **moist adiabatic rate**, then the air will be stable whether is unsaturated or saturated. This situation is called **absolutely stable**, since the air will always be stable.
- Similarly, if the environmental lapse rate is more negative than the dry adiabatic lapse rate, the air will always be unstable. This situation is called **absolutely unstable**, because the air is unstable regardless of whether it is unsaturated or saturated.

Conditional Instability



Air is stable to a certain height, however, if a "lifting mechanism" can cause air to rise, to a level where condensation is reached the air is now Saturated. When air becomes saturated it follows the moist adiabatic lapse rate!!

Conditional Instability

- The environmental (actual) lapse rate indicates stable air, with respect to the dry adiabatic value.
- This means that the atmosphere is stable as long as the air is not saturated. However, if the air were somehow able to rise far enough to become saturated, water vapor would begin to condense. This height is called the condensation level.

Conditional Instability

- From this point, the parcel would follow the moist adiabatic rate, which is less negative than the actual lapse rate in this case. So at this point the atmosphere is now unstable.
- If a parcel of air manages to reach the condensation level, it will be warmer than the surroundings and continue to rise. This situation is called **conditional instability**.
- When the atmosphere is conditionally unstable, it is unstable under the condition that air can be forced to rise to the level of condensation.

Mechanisms that Induce Rising Motion of Air Parcels:

- **Surface heating creating unstable air** (convection)
- **Air forced over topography — Orographic Lifting**
- **Collision of cold and warm air masses** (surface boundaries)
- **Convergence or divergence of air**

Review of Material

Stable Air

Defined by Slow Decrease or Increase of Temperature with Height

- Caused by Lack of Surface Warming or Surface Cooling
- Suppression of Rising Motions
- May Even Cause Sinking Motion

Unstable Air

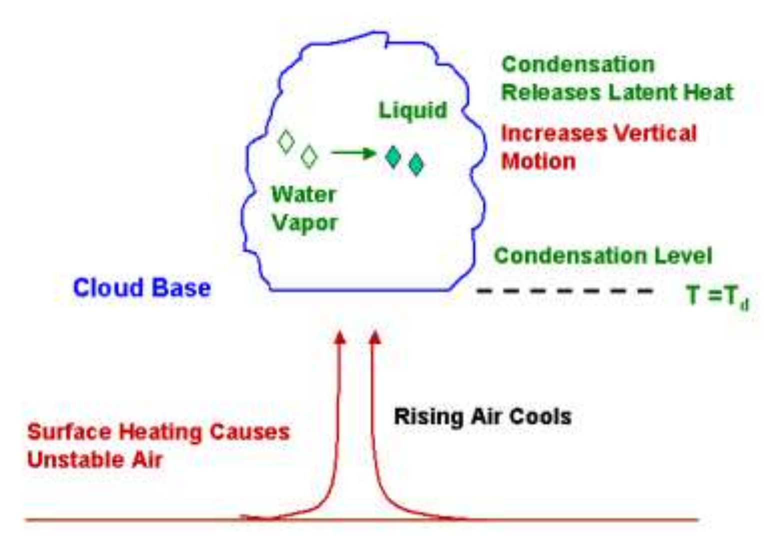
Defined by Rapid Decrease of Temperature with Height

- Caused by Surface Becoming Much Warmer than Air
- Enhances Rising Motions
- Strong Heating of Surface Produces Rising Air

Weather conditions and stable air

- Clearly stable air minimizes rising motions. The atmosphere is resistant to change. Such an atmosphere can be produced by either cooling the surface or warming the air above.
- The special case where temperatures actually increase with height in a layer of atmosphere is called an **inversion**.

Weather and unstable air



Formation of clouds favored by an unstable atmosphere.

Unstable air enhances rising motions caused by either heating the surface or moving colder air above it.

When saturation is reached, the water condensation releases latent heat. This adds buoyancy to the air making it rise even faster