The Atmosphere

Our studies begin with basic ingredients of Earth's contemporary atmosphere. The three main elemental components of the atmosphere are nitrogen (78%), oxygen (21%) and argon (1%). In addition to these three there are a number of trace elemental constituents including (in descending order): neon, helium, hydrogen, xenon. In terms of chemical compounds Earth's atmosphere is about 20% water vapor along with smaller amounts of carbon dioxide, methane, various nitrous oxides, ozone, particulates, and CFC's. Water vapor, methane and carbon dioxide are important *greenhouse gasses*.

The Earth's primordial atmosphere consisted of elemental hydrogen and helium along with the compounds methane, and ammonia. The most apparent differences between the Earth's primordial and modern atmospheres are the rise of oxygen and the decrease of hydrogen.

All gaseous molecules in the atmosphere are in constant motion. At a given temperature, lighter molecules have higher *root mean square* (rms) speeds than heavier molecules. If rms speeds are high enough some molecules may attain *escape velocity* and escape into space. Most light molecules, having higher rms speeds, escaped into space long ago. This accounts for the relative lack of hydrogen in the atmosphere in spite of its abundance elsewhere in the Universe. The rise of oxygen is due to the rise of plants, photodissociation reactions, and to a lesser degree the release of oxygen dissolved in ocean water. The modern atmosphere has been its current state for roughly 200-300 million years.

Outgassing from volcanoes provided the raw materials for formation of the atmosphere. Early volcanic activity liberated about 80% water vapor, 10% carbon dioxide, and 1-3% Nitrogen gas. Impacts from comets early in Earth's history are also though to account for a significant amount of water. Impacts from other large objects during the same period of time probably released large amounts of gas trapped in rocks in the earth's crust.

Layers of the Atmosphere

The earth's atmosphere has a discontinuous vertical structure. Three physical quantities are responsible for the vertical structure of the atmosphere: *density* (mass per unit volume), *atmospheric pressure* (the force the atmosphere exerts per unit area), and *temperature*. The density of the atmosphere decreases with increasing height. Atmospheric pressure, near sea level, is 14.7 pounds/square inch, 1013.25 mb, or 29.92 inches of Mercury (Hg). The *lapse rate* is the rate at which air temperature changes with height. In the *troposphere* (the layer of atmosphere closest to the earth's surface) the lapse rate is about 6.5^{o}C/1000m or 3.6^{o}F/1000ft.

The layers of the earth's atmosphere are divided (and subdivided) by variations in height, pressure, temperature, electrical properties and lapse rate. In terms of meteorology the layers of the atmosphere are the *Troposphere, Stratosphere, Mesosphere, Thermosphere, Exosphere, and Ionosphere*.

The *troposphere* is the layer of the atmosphere from the earth's surface up to about 11 km (0 - 7 mi.). All weather related phenomena (storms, fronts, clouds, etc.) occur within the troposphere. The troposphere is continually stirred by rising and descending air currents due to convective activity. Above the troposphere lies a region known as the *tropopause*. The tropopause separates the troposphere from the stratosphere. *Jet streams* are found in the tropopause.

The *stratosphere* extends from about 11 km to 49 km (7 – 30 mi.). In the lower part of the stratosphere, in a region known as the *isothermal* region, the lapse rate is zero. Higher up, near a height of 20 km, the air temperature begins to increase resulting in a *temperature inversion*. This inversion situated above the isothermal region acts as a trap and does not allow the vertical currents of air from the troposphere to spread into the stratosphere. This lack of convective motion results in stratification. Ozone (O_3) is an important constituent in the stratosphere. Stratospheric ozone helps to absorb much of the harmful UV light that in the atmosphere produced by the sun. During the past few decades the temperature inversion in the stratosphere has been waning and the amount of ozone diminishing.

The boundary between the stratosphere and the *mesosphere* is known as the *stratopause*. The mesosphere or "middle sphere" extents from about 49 km to about 86 km (30 – 54 mi). The percentage of Nitrogen and Oxygen is about the same in the mesosphere as it is at sea level but the atmospheric pressure is much lower. The lapse rate in the mesosphere is approximately $2^{o}C$/1000 m.

The *mesopause* marks the boundary between the mesosphere and the *thermosphere*. The thermosphere extends from about 86 km to 500 km (54 mi. – 300 mi.). Diatomic oxygen (O_2) in the thermosphere absorbs energetic solar rays (photons) which react exothermically to create heat. Great variations in temperature are found in the thermosphere due to the low density of this layer.

As one moves farther from the center of the earth gravity decreases. High in the atmosphere gravity is not as strong as it is near the earth's surface. The region in the atmosphere where large numbers of gas molecules have enough rms speed to escape into space is referred to as the *Exosphere*.

The higher layers of the earth's atmosphere are also known as the *ionosphere*. The ionosphere is not strictly speaking a layer of the atmosphere but an electrified region of charged particles. The ionosphere plays an important role in transmission of radio waves. The ionosphere is subdivided into the D layer at about 60 km, the E layer at about 120 km, and the F layer at about 180 km. At night, the D layer, which exists due to solar activity, disappears. The layers above the D layer reflect AM radio waves very effectively. This is why distant AM radio stations may be heard at night.

Weather Maps

The Earth's surface may be parceled into grids defined by lines of *longitude* and *latitude*. *Meridians*, or lines of longitude, run from north to south. *Parallels*, or lines of latitude, run from east to west. The latitudes from 30^{o} – 50^{o} N are known as the *middle latitudes*. Weather features on or above the earth's surface are usually located by their latitude and longitude.

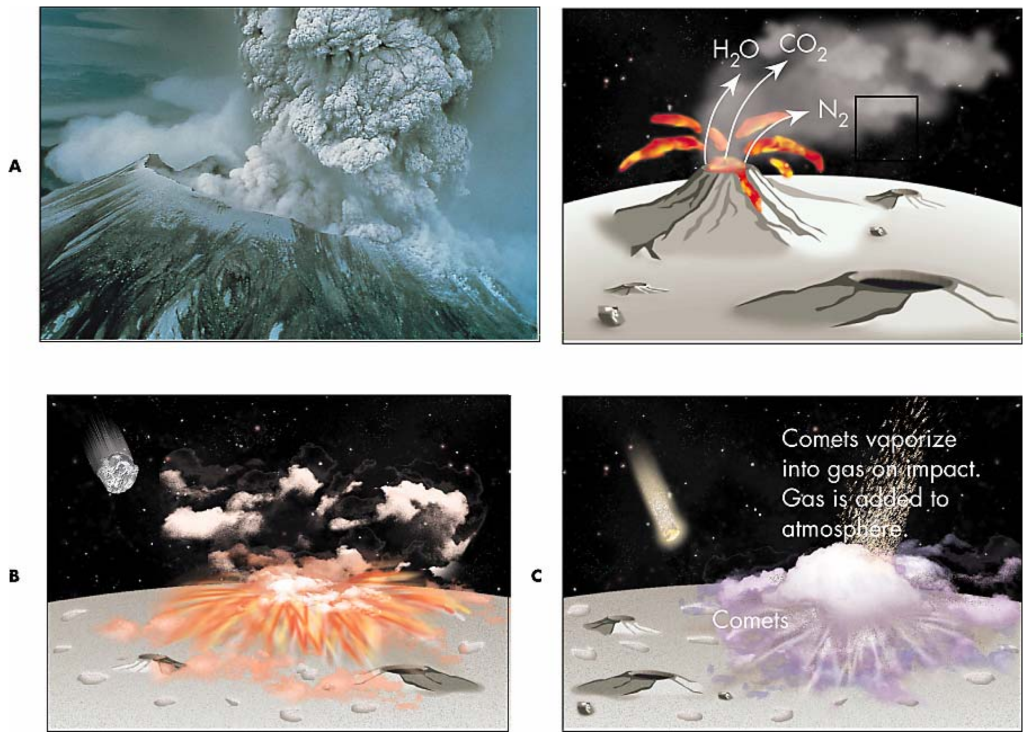
Geostationary satellites allow meteorologists a "bird's eye" view of the weather on the earth. Placed at an altitude of 22,300 miles, geostationary satellite orbit at the same rate as the spin of the earth. The stationary nature of the orbit allows geostationary satellites to stay positioned over the same position indefinitely. Data from geostationary satellites is often used to create weather maps.

Fronts are important weather elements and are found on all weather maps. *Cold fronts* form where colder air replaces warmer air. *Warm fronts* form where warmer air is overtaking colder air. When a cold front overtakes a warm front the result is an *Occluded Front*. Fronts are characterized by rising air that condenses and results in clouds and precipitation.

High Pressure Systems (marked with an H) and *Low Pressure Systems* (marked with an L) are important weather makers. In the Northern Hemisphere high-pressure systems rotate clockwise while low-pressure systems rotate counterclockwise. Low pressure systems (for reasons that will become clear later) are usually associated with overcast days and precipitation. High pressure systems are associated with clear, sunny days.

More on the Atmosphere/Oceans of the Earth

- The primordial atmosphere was rich in nitrogen, carbon dioxide, hydrogen rich compounds such as methane and ammonia and water vapor
- The primordial atmosphere formed when these gasses were liberated from the earth's interior due to collisions and volcanic activity. Comets may have also contributed water to the primordial atmosphere. Methane and ammonia were broken down into hydrogen, carbon and nitrogen by sunlight. Most of the nitrogen and carbon remains while the hydrogen long ago escaped into space.



(Courtesy of Thomas Arny)

- The modern atmosphere is relatively oxygen rich (about 78% nitrogen and 21% oxygen). Oxygen came from the rise of organisms (plants).
- The earth has oceans. Primordial oceans formed when water vapor in the atmosphere cooled as the planet cooled and condensed into liquid water.

Details of Earth's Atmosphere

- Earth's atmosphere has four layers: the *Troposphere, Stratosphere, Mesosphere and Thermosphere.*
- The lowest layer of Earth's atmosphere, the one in which all weather (and life) exists is the *troposphere*. The troposphere extents from the surface to about 10 kilometers above the ground. Temperature decreases with increasing height in the troposphere. This *lapse rate* is about 5.5^{0}F per 1000 feet on average. The troposphere is capped by the *tropopause* which is notable for being the layer of Earth's atmosphere containing *jet streams*.
- The *stratosphere* lies above the troposphere and is important to life because stratospheric ozone (O_3) is largely responsible for absorbing ultraviolet radiation from the sun. The stratosphere extends to about 50 kilometers above the earth's surface. There is a temperature inversion in the stratosphere (although this inversion is weakening due to *global warming*). The stratosphere is capped by the *stratopause*.
- The *mesosphere* extends to about 85 kilometers above the earth's surface. The mesosphere also cools with increasing height.
- The *thermosphere* fades gradually into outer space 120 kilometers up. The thermosphere is also characterized by a strong temperature inversion and is the warmest layer of Earth's atmosphere.
- Temperature decreases with height in the earth's atmosphere in the troposphere and mesosphere but *increases* with height in most of the stratosphere and all of the thermosphere.

Summary of How the Sun Transmits Energy to Earth

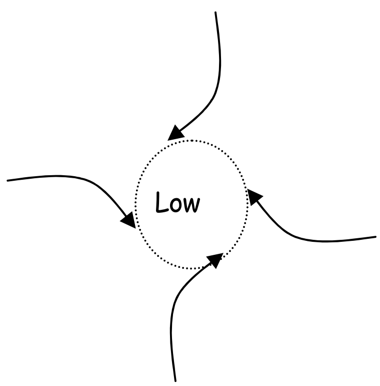
- There are three mechanisms by which energy is transmitted: *conduction, convection and radiation*.
- Conduction is a mechanism of energy transfer that occurs when two objects that have different temperatures are placed in direct contact with one other. Heat energy flows from the hotter object to the cooler object.
- Convection is a mechanism of energy transfer that occurs in fluids. Convection occurs when a fluid begin a "roiling" motion when part of it is heated like that seen in a pot of boiling water on a stove. The roiling motion distributes heat from the hotter regions of the fluid to the cooler regions of the fluid.
- Radiation is energy transfer via electromagnetic waves. The infrared heat from an electric heater is an example of heat transfer via radiation as is the warmth you feel outside from the sun on a clear day.
- Energy in the sun is created in the thermonuclear core and is transmitted outward to the surface of the sun (the *photosphere*) via radiation and convection.

- The sun is a blackbody whose surface temperature may be determined from its color via Wiens Law (about 5800K).
- The sun pumps out an amazing 4×10^{26} watts of power. This energy is radiated away from the sun in all directions.
- Energy from the surface of the sun reaches the top of the earth's atmosphere via electromagnetic radiation (sunlight). Due to the inverse square law, the amount of power from the sun which reaches the top of earth's atmosphere is about 1400 watts/m^2.
- Earth's atmosphere generally absorbs very little sunlight. About 1000 watts/m^2 of power from the sun eventually reaches the earth's surface in the middle latitudes (under ideal conditions).
- Since the atmosphere is nominally transparent to visible light it is the presence of aerosols and clouds that reflect and scatter the 30% of sunlight that does not penetrate the atmosphere.
- The average amount of sunlight that reaches the earth's surface worldwide is about 340 w/m^2.
- Of the sunlight that reaches the earth's surface, approximately 1/3 is absorbed and converted to IR (blackbody effect) – about 110 watts/m^2. The remaining sunlight is reflected/scattered back into the atmosphere from the earth's surface.
- The earth warms all during the day (while it is being illuminated) and radiates well after sunset.
- Earth's atmosphere absorbs and scatters IR (the greenhouse effect), thus heating the environment. Greenhouse gasses include water vapor, carbon dioxide and methane.
- The atmosphere is also heated by conduction in the *boundary layer*. The boundary layer is the layer of air within a meter of so of the ground. Although air is generally not a good conductor of heat, the amount of air in contact with large patches of ground eventually becomes heated due simply to the large areas involved.
- On a warm sunny day temperature gradients in the boundary layer can be as great as 40^0 F in less than a meter!
- Warm air is less dense than cool air, is more buoyant, and will rise. On clear, calm days thermal bubbles of warm air rise over portions of the earth's surface warmed by direct sunlight.
- These thermal bubbles contain air and water vapor. As they rise they cool at approximately the lapse rate of 5.5^0 F per 1000 feet in the troposphere. As they cool the water vapor in these air masses condenses to water droplets. This begins the process of cloud formation.
- Condensation liberates *latent heat.* The release of latent heat is a significant contributor to Earth's overall temperature. Latent heat is also a significant energy source for thunderstorms as the release of latent heat from

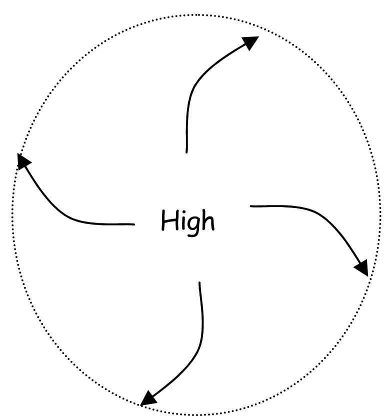
condensation enhances thermal activity and results in large amounts of vertical air movement in the atmosphere. Hurricanes are examples of large weather systems fueled by the release of latent heat.

- Thermal activity in Earth's atmosphere distributes heat from the sun vertically and from the equatorial regions northward where warming of the surface is less efficient.
- Vertical motion of air creates High and Low Pressure regions. Horizontal movement of air both near the surface and at higher elevations creates fronts, long waves, and jet streams. All of these features distribute heat throughout the atmosphere.
- Most large (mesoscale or greater) weather systems rotate due to the *Coriolis Force.* The Coriolis force is an apparent deflection to the right that affects all air masses due to the rotation of the earth.

High and low pressure systems



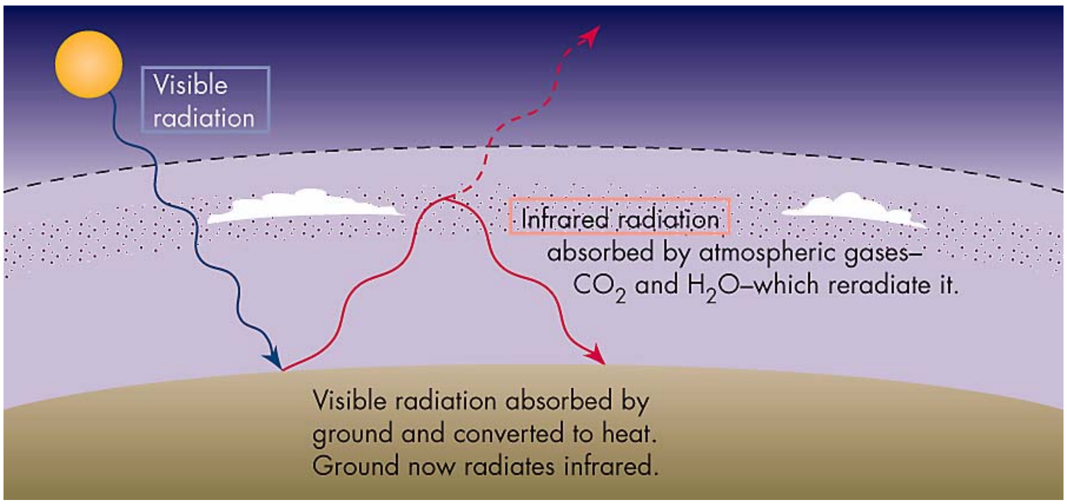
ccl rotation



cl rotation

Summary of the Greenhouse Effect

- Earth, Venus, Mars all have greenhouse gasses in their respective atmospheres
- A greenhouse effect, due to the partial opacity of the atmosphere to infrared light, helps moderate temperature on earth.



(Courtesy of Thomas Arny)

- Although Earth has always had a "greenhouse effect", human activities are increasing both the amount of greenhouse gasses in Earth's atmosphere and the infrared signature of Earth's surface, thus enhancing the existing greenhouse effect
- Global warming is a well- established scientific fact
- Increasing CO_2 levels (and other greenhouse gasses) have been thoroughly documented.
- Increase of Earth's infrared signature has been thoroughly documented
- Increasing global temperatures have been thoroughly documented

Possible Effects of Human Enhancement of Earth's Atmosphere

- Increase in sea levels
- Climate change
- Increases in storm energy
- Increases in disease
- Global cooling