

## Chapter 31: The Atmosphere, The Oceans, and Their Interactions

### 31.1. Earth's Atmosphere and Oceans

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### 31.1. Earth's Atmosphere and Oceans

- 70% of the earth's surface is covered by water
- Most land is in the northern hemisphere
- Oceans tend to maintain earth's temperature
- Water has a high heat capacity; it is slow to heat up or cool down
- Land near oceans has less temperature variation
- Coastal vs. continental weather

### Evolution of the Earth's Atmosphere and Oceans

- Primitive atmosphere mainly hydrogen and helium with traces of ammonia and methane

- The primitive sun began to generate heat with nuclear fusion and its radiated heat blew away much of the earth's early atmosphere
- Later outgasing from volcanoes added a mix of 85% H<sub>2</sub>O, 10% CO<sub>2</sub>, and 5% N<sub>2</sub>
- Some CO<sub>2</sub> is absorbed by the oceans and converted to limestone
- Early plant life used photosynthesis to convert atmospheric CO<sub>2</sub> to oxygen:  $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2$
- This gradually created our present nitrogen-oxygen atmosphere
- It also led to a O<sub>3</sub> ozone layer which protects the earth's surface from ultraviolet solar energy
- The water vapor formed rain and created our present oceans

## 31.2. Components of the Earth's Atmosphere

- Air molecules move at 450 m/s near the earth's surface
- Air molecules have enough energy to rise to 50 km, but almost always run into slower air molecules before they get that far
- The earth's gravity compresses the air and holds most of it within the lowest 10 km of sea level
- This means that air density drops off rapidly with altitude
- The pressure of the air at the earth's surface is really the weight of the air above us
- The composition of the earth's atmosphere (by volume) is:  
Nitrogen 78%  
Oxygen 21%  
Argon 0.9%  
Water Vapor 0-4%  
Carbon Dioxide 0.035%
- There are trace amounts of Neon, Helium, Methane, Hydrogen, & Ozone

## Vertical Structure of the Atmosphere

- 50% of the atmosphere is below 5.6 km

- 99% of the atmosphere is below 30 km
- The lowest level of the atmosphere is the troposphere
- The troposphere extends to 16 km in the tropics and 8 km in the polar regions
- The temperature in the troposphere drops 6 °C per kilometer with the top of the troposphere getting down to -50 °C
- Jets fly at the top of the troposphere to avoid weather turbulence
- The troposphere holds 90% of the atmosphere's mass and all of the clouds and water vapor
- The next layer is the stratosphere which extends from 16 km to 50 km
- The ozone layer which absorbs ultraviolet radiation is in the stratosphere at 30 km
- This causes the temperature in the stratosphere to rise from -50 °C at the bottom (16 km) to 0 °C at the top (50 km)
- The air temperature drops again from 0 °C to -90 °C in the mesosphere (50 to 80 km)
- Above this is the thermosphere (80-500 km) where the temperature is very high (2000 °C)
- But the air density is so low that not much heat would be transferred to an object moving through the thermosphere
- The upper part of the thermosphere is called the ionosphere because there is enough light to strip the electrons from the atoms but too low a density of ions to recombine
- The aurora borealis and aurora australis are light displays caused by radiation moving through the air at high speed
- The exosphere is the part above 500 km extending to the Van Allen radiation belts
- Layers of the Atmosphere
  - Troposphere (ground to 16 km, clouds)
  - Stratosphere (16 to 50 km, ozone)
  - Mesosphere (50 to 80 km)
  - Thermosphere (80 to 500 km) (includes ionosphere)
  - Exosphere (above 500 km)

### 31.3. Solar Energy

- The tropics are warmer because the light from the sun hits directly, not obliquely
- Mid and polar latitudes are cooler since the sun's light hits obliquely and the same amount of light is spread over a larger area

### The Seasons

- The degree of obliquity (angle of the sun) varies with the seasons
- The earth's tilt (axial) of  $23.5^\circ$  means that the sunlight hits the northern hemisphere more obliquely in winter, more directly in summer
- The equinoxes are the days when the night and day times are equal
- The summer solstice is the day when the daylight is a maximum and the night time is a minimum
- The winter solstice is the day when the night time is a maximum and the daylight is a minimum
- The equinoxes occur on or near the 21st of March and September
- The summer solstice is on or near June 21st and the winter solstice is on or near December 21st
- Although December 21st is the start of winter in the northern hemisphere, the earth is actually slightly nearer to the sun at that time
- So the angle of the sun's rays is more important than the distance to the sun
- The  $23.5^\circ$  line north or south of the equator marks the edge of the tropics and is the farthest point from the equator at which the sun can be directly overhead (at noon on the summer solstice)
- The Arctic and Antarctic Circles mark the farthest point away from the poles at which the nights can last a full 24 hours in winter

### Terrestrial Radiation

- Sunlight is rich in UV (ultraviolet radiation)

- Some sunlight is absorbed directly by the air
- Most sunlight reaches the ground and is absorbed there
- Sunlight absorbed by the ground is re-radiated as IR (infrared radiation)
- This IR is called terrestrial radiation and heats the lower atmosphere
- In the daytime the air heats up near the ground
- At night the air cools rapidly as the heat from the ground radiates into the upper atmosphere
- The nighttime cooling is reduced by high air humidity and cloud cover which blocks the escape of the IR

## The Greenhouse Effect and Global Warming

- Greenhouses keep warm in winter by allowing the UV to go through the glass but trapping the heating IR which can't penetrate the glass
- Some trace gases in the atmosphere act the same
- Greenhouse gases pass UV but absorb and trap IR
- Without the greenhouse effect, the earth's surface would average -18 °C
- The main greenhouse is water vapor (H<sub>2</sub>O), but this is not usually mentioned as it is not controllable
- After water vapor, the most important greenhouse gases are CO<sub>2</sub>, CH<sub>4</sub>, CFC's, and NO<sub>2</sub>
- The CO<sub>2</sub> concentration in the atmosphere is about 350 PPM
- This is up about 30% over the last 300 years
- The earth's temperature varies naturally also
- Currently we are in a colder than average phase due to the polar ice caps
- The earth's temperature would have to rise a few degrees Celcius to reach the average over the last billion years
- Various unproven theories of global warming suggest that serious effects could occur from the continuing build-up of greenhouse gases in the atmosphere
- Other theories suggest that we could soon be headed back into the Ice Ages that have dominated the earth for the last million years or so

## 31.4. Driving Forces of Air Motion

- Warm air is less dense than cold air and tends to rise
- Cold air is more dense than warm air and tends to fall
- This unevenness causes an up-down air flow which tends to mix the air and even out temperatures
- This natural air flow of rising warm air and falling cold air is called convection
- A difference in pressure between two points is called a pressure gradient
- Pressure gradients drive air flow from higher pressure to lower pressure
- When one area is heated by sunlight hitting the ground, the hot air has greater pressure and expands upward
- The rising hot air becomes less dense as it expands upward
- The rising hot air creates a lower pressure at ground level and draws in cold air along the surface
- The risen hot air is at a higher pressure than the surrounding cold air at altitude
- Thus the hot air at altitude flows toward the colder areas
- This completes the convection cycle and creates a continuous flow of hot upper level air toward colder areas and cold surface air toward warmer areas

### Large Scale Air Movement

- The sun heats the earth unevenly due to the obliquity of sunlight at higher latitudes
- This uneven heating creates large convection cells that cover most of the earth
- In general, hot air rises in the tropics, cools, and descends at the poles
- But the atmospheric convection cells are not quite continuous from tropics to poles
- Another important effect is due to the rotation of the earth
- The earth spins on its axis once per day

- The circumference of the earth is about 40,000 km at the equator
- Thus a point on the equator is traveling 40,000 km per day or about 1670 km/hour
- We don't notice this because of gravity and because the atmosphere at the equator is traveling along with us
- But the earth's speed at the poles is zero
- So the air at the poles isn't moving like that at the equator
- Air that rises or moves toward the equator lags behind the air already there and this lag appears as an apparent rightward spin as seen from the earth's surface
- Descending air reverses this effect and has an apparent leftward spin
- The effect that causes this is called the Coriolis Force
- Winds thus deflect to the right in the northern hemisphere
- Air in a high pressure area moves away from the center and its spin to the right is clockwise
- Air in a low pressure area moves toward the center and its spin to the right is counterclockwise
- Large storms tend to be centers of low pressure and their winds are counterclockwise
- The Coriolis Effect is greatest at the poles and diminishes toward the equator
- The friction of the winds moving across the earth's surface slows their speed and reduces the effect of the Coriolis Force
- The Coriolis force only affects large bodies of water

### 31.5. Global Circulation Patterns

- Since most of the hot air in the tropics simply rises, the surface winds are usually mild (except during storms)
- The doldrums are the tropical region of no wind due to the calm surface air
- The hot, moist air from the tropics carries a lot of energy and can produce powerful tropical storms as it rises

- The hot, moist tropical air rises to the top of the troposphere and then moves north or south toward the poles
- The cooled air descends toward the ground around 30° north or south latitude
- This produces a band of hot, dry, slow moving air around that latitude
- This band is called the horse latitudes
- The area between the doldrums and the horse latitudes is called the "trade winds"
- Moving from the horse latitudes toward the poles, a region called the "westerlies" is encountered
- Near the poles, the polar air descends and generally moves toward the east
- The middle "westerly" latitudes have unpredictable weather
- Sailing vessels on the Atlantic used the trade winds to go from Europe to America and the westerlies to return

## Upper Atmospheric Circulation

- The upper troposphere has "rivers" of air moving at 95-190 km/hr
- These "jet streams" are from 9-14 km high
- The jet streams help to transfer heat from the tropics to the poles
- Jet streams are the result of the thermal gradient at the polar front - the 60° latitude boundary between the westerlies and the polar easterlies
- The temperature gradient increases the wind speed
- The polar jet stream moves to lower latitudes in winter
- In summer it is weaker and more toward the poles
- There is also a subtropical jet stream that creates the monsoons over southern Asia
- This subtropical jet stream begins at the 30° latitude boundary between the trade winds and the westerlies
- The subtropical jet stream is related to the rising air over the Asian continent in the summer
- This pulls the hot, moist, subtropical air from the Indian ocean onto the land

- There it rises and cools forming tropical thunderstorms
- During winter, the flow reverses

## Oceanic Circulation

- Surface ocean currents are driven by the wind
- Currents are altered by running into continental shorelines
- Deeper currents are driven by water density differences
- Density is affected by water temperature and the concentration of dissolved salts (called salinity)
- Dissolved salts constitute 99%+ of all the chemicals in sea water
- Salinity is given as the mass of salts per kilogram of seawater
- Typical salinity is 3.5% or 35 grams per kilogram of seawater
- There is some variation due to inputs of fresh water from rivers, rain/snow, glacial ice melts, and freezing of seawater
- Oceans are divided vertically into the surface, transition, and deep water layers
- Pressure changes dramatically with depth
- Colder water is also denser
- The % of dissolved sea salts by weight is:
 

Cl <sup>-</sup>	55.07
Na <sup>+</sup>	30.62
SO <sub>4</sub> <sup>2-</sup>	7.72
Mg <sup>2+</sup>	3.68
Ca <sup>2+</sup>	1.17
K <sup>+</sup>	1.10

## Surface Currents

- Winds drive surface currents
- Over long distances, the Coriolis Effect produces a spiral called a gyre
- In the northern hemisphere the gyres circulate clockwise
- In the tropics, the trade winds drive the surface currents westward

- When the currents run into a continent, the current splits with part going north and part going south
- In the temperate latitudes, the westerlies drive the currents eastward
- In the northern hemisphere, the combination of trade winds and westerlies create enormous gyres
- With less land in the southern hemisphere, temperate to polar latitude currents circle the globe in an eastward flow
- The huge, ocean spanning gyres transport heat from the equator to higher latitudes
- In the north Atlantic Ocean, warm currents from the Gulf of Mexico flow northward along the east coast of the United States
- This current is called the Gulf Stream
- The Gulf Stream then crosses the Atlantic and warms Western Europe before turning south and recrossing the Atlantic to complete the cycle
- Similar currents occur in the South Atlantic Ocean and in both hemispheres of the Pacific Ocean

## Deep-Water Currents

- Deep water currents are driven by gravity
- Density differences cause denser waters to sink
- The deep water flow is slower than the surface current flow
- There is a very slow, worldwide north-south circulation pattern
- Seawater can freeze near the poles
- When seawater freezes, it forms pure water ice and excludes the salts
- The excluded salts remain in the seawater which becomes saltier and denser thereby
- This more saline seawater is produced near the north pole and sinks due to its greater density
- The sinking saline rich seawater flows to the North Atlantic deeps near the north pole and then flows south to Antarctica
- From Antarctica the deep current flows north through the Indian and Pacific Oceans

- Now warmed and less saline, the deep current returns to the North Atlantic to repeat the cycle
- This deep current is believed to have about a 40 year cycle time
- This deep current is believed to affect long term weather patterns and may account for the small increase in world temperature in the 1990's

## **El Niño Condition/La Niña**

- Normally, high pressure equatorial areas in the Pacific cause westward moving trade winds
- This brings up cold, nutrient-laden water and fish in the eastern Pacific off of South America
- The trade winds slacken in October and fishing declines near Christmas
- This decline is called El Niño as it occurs near the El Niño (the Christ Child) celebration in South America
- Sometimes, warm surface conditions off South America persist for years
- This causes a prolonged El Niño condition
- Usually, the western Pacific has warm, moist surface air and high precipitation
- An El Niño sends the warm surface water to the eastern Pacific and increases rainfall in western North and South America
- The reverse of the El Niño condition is the La Niña
- The El Niño/La Niña change is called the southern oscillation