Chapter 3

Atmosphere

Standard 3: Students will understand the atmospheric processes that support life and cause weather and climate.

Standard 3, Objective 1: Relate how energy from the Sun drives atmospheric processes and how atmospheric currents transport matter and transfer energy.

Objectives

- Compare and contrast the amount of energy coming from the Sun that is reflected, absorbed or scattered by the atmosphere, oceans, and land masses.
- Construct a model that demonstrates how the greenhouse effect contributes to atmospheric energy.
- Conduct an investigation on how the tilt of Earth's axis causes variations in the intensity and duration of sunlight striking Earth.
- Explain how uneven heating of Earth's atmosphere at the equator and polar regions combined with the Coriolis effect create an atmospheric circulation system including, Hadley cells, trade winds, and prevailing westerlies, that moves heat energy around Earth.
- Explain how the presence of ozone in the stratosphere is beneficial to life, while ozone in the troposphere is considered an air pollutant.

Terms to know

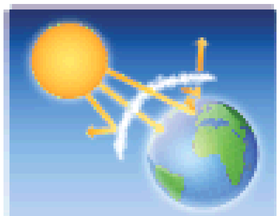
- reflected
- absorbed
- scattered
- atmosphere
- greenhouse effect
- Coriolis effect
- Hadley cells
- trade winds
- prevailing westerlies
- ozone
- stratosphere
- troposphere
- air pollutant

Is the Greenhouse Effect a Good Thing or a Bad Thing?

Introduction

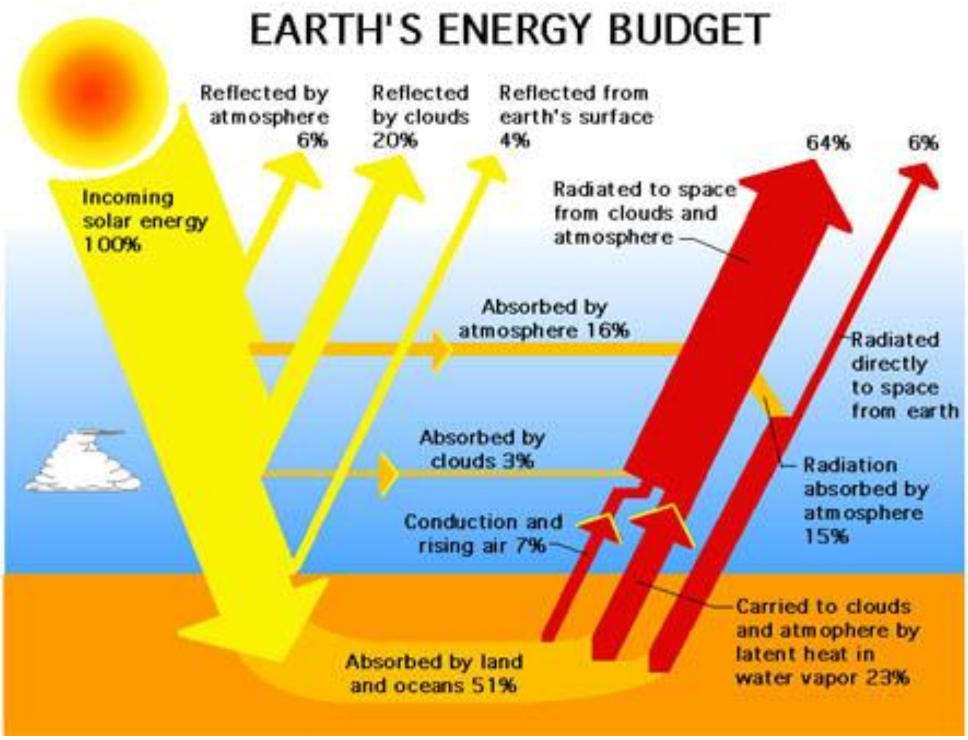
Why is Earth the only planet in the solar system known to have life? The main reason is Earth's atmosphere. The atmosphere is a mixture of gases that surrounds the planet. We also call it air. The gases in the air include nitrogen, oxygen, and carbon dioxide. Along with water vapor, air allows life to survive. Without it, Earth would be a harsh, barren world.

Section 1: The Atmosphere and the Sun's Rays



The atmosphere protects living things from the sun's most harmful rays. Gases reflect or absorb the strongest rays of sunlight.

The atmosphere shields Earth from harmful solar rays.



The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers indicate a measurement of energy and the arrows depict the direction of the movement of the energy.

The Atmosphere and Earth's Temperature

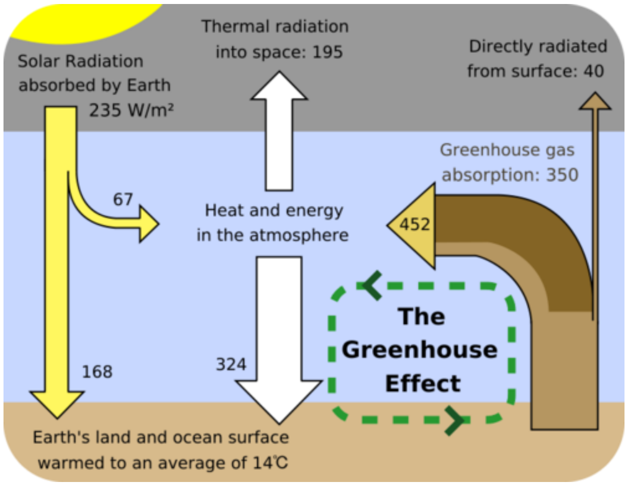
Gases in the atmosphere surround Earth like a blanket. They keep the temperature in a range that can support life. The gases keep out some of the sun's scorching heat during the day. At night, they hold the heat close to the surface, so it doesn't radiate out into space.

How does the atmosphere resemble a greenhouse?

To extend the growing season, many farmers use greenhouses. A greenhouse traps heat so that days that might be too cool for a growing plant can be made to be just right. Similar to but not exactly like a greenhouse, the greenhouse gasses in our atmosphere absorb energy that is emitted by the Earth and then radiate the energy back to the Earth at a different wavelength- thus keeping the Earth at a habitable temperature.

The Greenhouse Effect

The role of **greenhouse gases—(gases that absorb and emit heat)—**in the atmosphere is very important in balancing Earth's temperature. **Greenhouse gases** warm the atmosphere by absorbing and re-emitting heat. Some of the heat that radiates out from the ground is absorbed and re-emitted by greenhouse gases in the troposphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of insulation by greenhouse gases is called the greenhouse effect (see Figure below). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.



Greenhouse Gases

Greenhouse gases include carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), ozone (O_3), nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. The table on the next page shows how each greenhouse gas naturally enters the atmosphere.

Greenhouse Gas Entering the Atmosphere	
Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere and has increased by over 40% since the industrial revolution.

Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 250% higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

For additional help check out this PowerPoint review, Atmospheric Energy and Global Temperatures, it looks at the movement of energy through the atmosphere

http://www.youtube.com/watch?v=p6xMF_FFUU0 (8:17).

An additional diagram is found at
http://www.amnh.org/explore/ology/climatechange

Lesson Summary

- Greenhouse gases include CO2, H2O, methane, O3, nitrous oxides (NO and NO2), and chlorofluorocarbons (CFCs).
- Tropospheric greenhouse gases trap heat in the atmosphere; greenhouse gases vary in their heat-trapping abilities.
- Levels of greenhouse gases in the atmosphere are increasing due to human activities.
- Increased levels of greenhouse gases lead to increased average global temperatures.

Practice: Use this resource to answer the questions that follow.

`http://www.hippocampus.org/Earth Science → Environmental Science →Search: Greenhouse Effects (first resource, starts with "About 50% of solar radiation...")`

Think like an Environmental Scientist

1. What percentage of solar radiation is absorbed by the surface of the Earth?

2. What is reflection and how does it affect the amount of energy in the atmosphere?

3. In what form does most of the sun's energy reach the earth's surface? How is it re-emitted?

4. What are the main greenhouse gases? How do greenhouse gases affect life on Earth?

5. If you were trying to keep down global temperature and you had a choice between adding 100 methane molecules or 1 CFC-12 molecule to the atmosphere, which would you choose? Why?

6. Is greenhouse effect a good thing or a bad thing? Defend your answer.

How Does Heat on Earth Resemble a Household Budget?

After the sun's energy enters the Earth's atmosphere the heat is either **absorbed–(taken in, reflected–hitting a barrier and bouncing off), or scattered–(hitting a barrier and bouncing off in many different directions)**. The heat left on Earth is equal to the amount of heat absorbed minus the amount of heat given off. If more energy comes into the system than goes out of the system, the planet warms. If less energy goes into the system than goes out of the system, the planet cools. Replace the word "money" for "heat" and "on Earth" to "in your bank account" and you describe a household budget. Of course, Earth's heat budget is a lot more complex than a simple household budget.

Section 1: Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths of energy can only be seen by infrared sensors.

The basics of Earth's annual heat budget are described in this video:

`http://www.youtube.com/watch?v=mjj2i3hNQF0&feature=related (5:40)`

The Heat Budget

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception), because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in? To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See the Table below

The Amount of Incoming Solar Energy				
	Day Length	Sun Angle	Solar Radiation	Albedo (reflected energy)
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

This animation shows the average surface temperature across the planet as it changes through the year:

Monthly Mean Temperatures

http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif

Lesson Summary

- The amount of energy received at the poles and at the equator is different.
- More solar radiation strikes the equator than the poles.
- To keep the earth's temperatures relatively constant the amount of energy coming into the atmosphere must eventually be re-radiated to space.
- Incoming solar radiation is absorbed by atmospheric gases; reflected by clouds, the ground, and atmosphere; or scattered.
- Much of the radiation that strikes the ground is radiated back into the atmosphere as heat.

Think Like an Environmental Scientist

1. What happens to our planet if more heat is absorbed than reflected/radiated?

2. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?

3. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?

4. What happens to sunlight when it hits the ground?

5. Because solar energy is continuously entering the Earth's atmosphere and ground, why is the planet not getter hotter?

6. How is the albedo affected by snow and ice?

Practice

Use this resource to answer the questions that follow: http://www.youtube.com/watch?v=JFfD6jn_OvA

7. What does CERES measure?

8. What does the acronym CERES stand for?

9. What is the ideal radiation budget?

10. How much of the sun's radiation is reflected?

11. How much energy does the ocean absorb?

12. What are scientists finding with CERES?

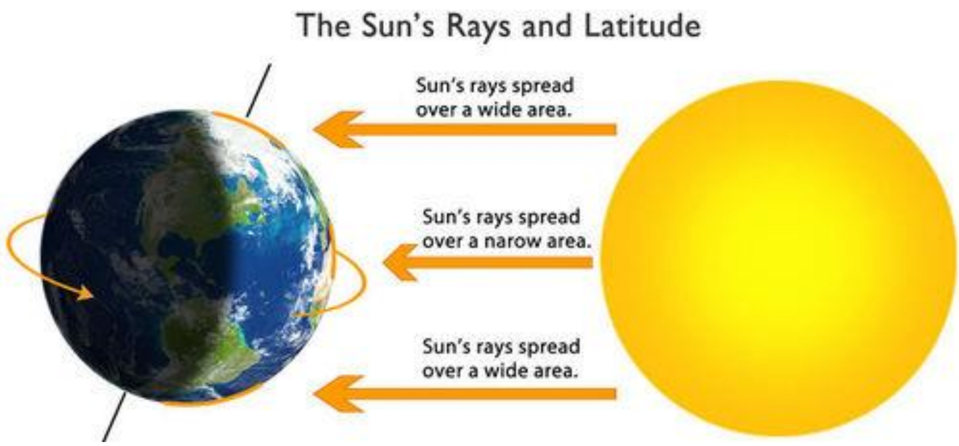
13. Why is the Earth warming?

14. What is a carbon footprint?

Why is it winter in the Southern Hemisphere when it is summer in the Northern Hemisphere?

The sun is always up, even in the middle of the night in Antarctica during the summer. The photo on the left is Antarctica during the night in the summer. The photo on the right is Antarctica during the day in summer. Similarly, in the winter Antarctica is mostly dark all day.

Different parts of Earth's surface receive different amounts of sunlight. You can see this in the Figure below. The sun's rays strike Earth's surface most directly at the equator. This focuses the rays on a small area. Near the poles, the sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives and the warmer it is. Another way to word this is that towards the poles there is a greater amount of area that receives that same amount of sunlight.



Near the poles the sun's rays always strike the ground at an angle. Near the Equator the rays are more perpendicular. In this diagram, what season it in Utah? The difference in solar energy received at different latitudes drives atmospheric circulation. Places that get more solar energy have more heat. Places that get less solar energy have less heat. Warm air rises and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.

Lesson Summary

- Solar energy that reaches Earth near the equator is more direct and therefore, more concentrated.
- Solar energy that reaches Earth near the poles is at an angle and therefore, less concentrated.
- The difference in the amount of solar energy drives atmospheric circulation.

Practice

Use this resource to answer the questions that follow.
http://www.kidsgeo.com/geography-for-kids/0074-latitude-effects-temperature.php

Think like a Climatologist

1. What is latitude?
2. How does latitude affect global temperatures?
3. What part of Earth receives the most solar radiation in a year?
4. Why do cities near the Arctic Circle (70°N) rarely have temperatures above 36°C (96°F) even though the sun shines almost 24 hours a day?
5. How does uneven heating of the earth affect global circulation?

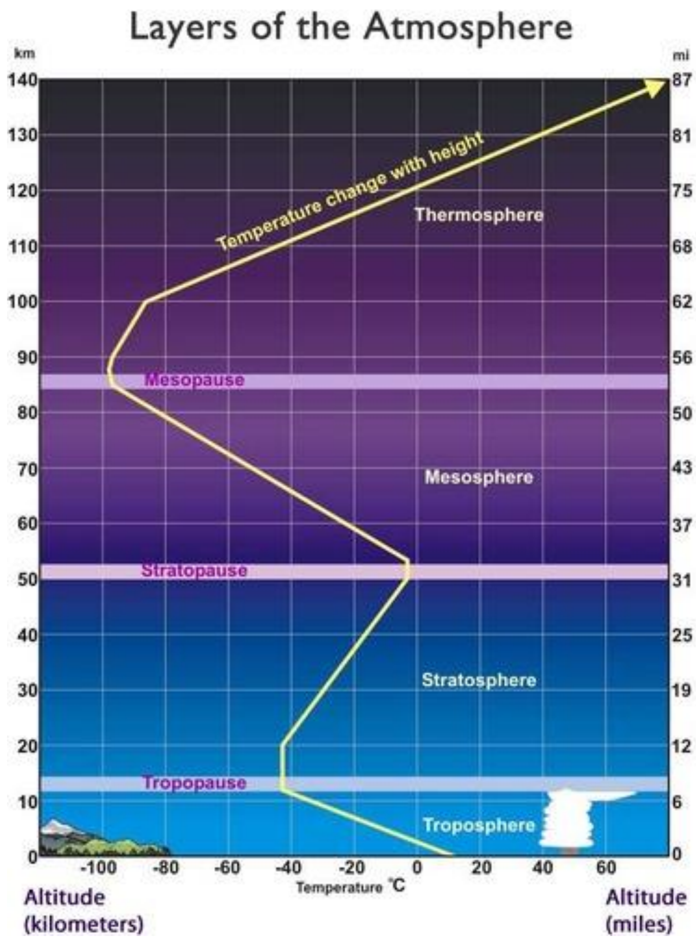
6. The North Pole receives sunlight 24 hours a day in the summer but less solar radiation than the equator. Explain why.

What Makes the Wind Blow?

Why do we say Earth's temperature is moderate? It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air toward the poles and frigid polar air toward the equator. If the planet had an atmosphere that was stagnant (not moving), the difference in temperature between the two regions would be much greater.

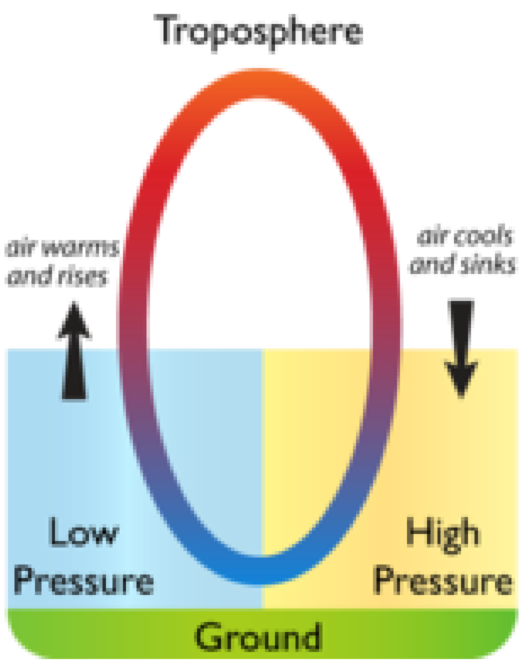
Section 1: Layers of the Atmosphere

The atmosphere is divided into various layers (as seen below). Weather happens in the lowest layer or the Troposphere.


Layers of the Atmosphere
km
mi
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
87
81
75
68
62
56
50
43
37
31
25
19
12
6
0
Temperature change with height
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
-100
-80
-60
-40
-20
0
20
40
60
Temperature °C
Altitude
(kilometers)
Altitude
(miles)

Air Pressure Zones

Within the troposphere are convection cells (see Figure below). Air heated at the ground rises, creating a low pressure zone. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at the top of the troposphere. The air cools until it descends. When the air reaches the ground, it creates a high pressure zone. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

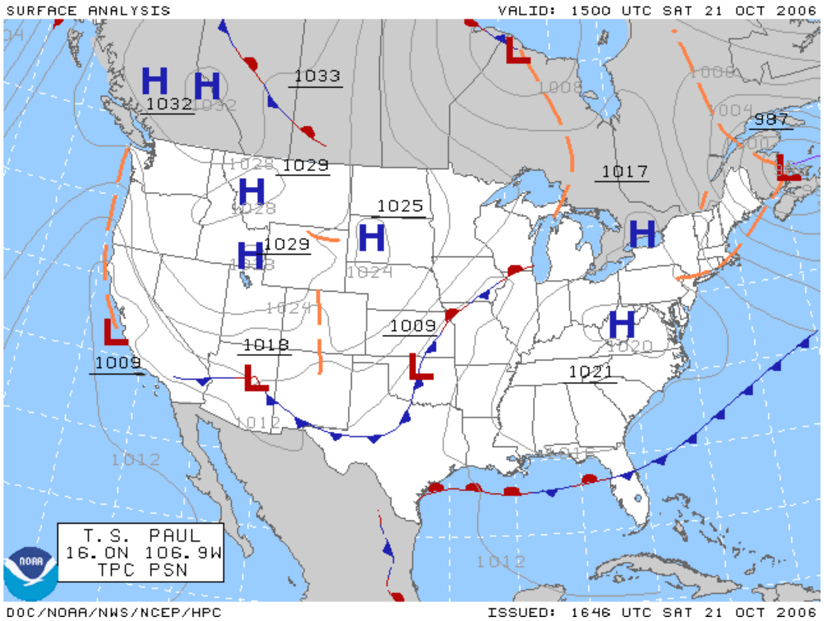


Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

Warm air can hold more moisture than cool air. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

High and Low Pressure Systems

Pressure systems cause the day-to-day weather experienced locally. Low-pressure systems are associated with clouds and precipitation that minimizes temperature changes through the day, whereas high-pressure systems normally associated with dry weather and mostly clear skies with larger diurnal temperature changes due to greater radiation at night and greater sunshine during the day. Pressure systems are analyzed by those in the field of meteorology within surface weather maps.



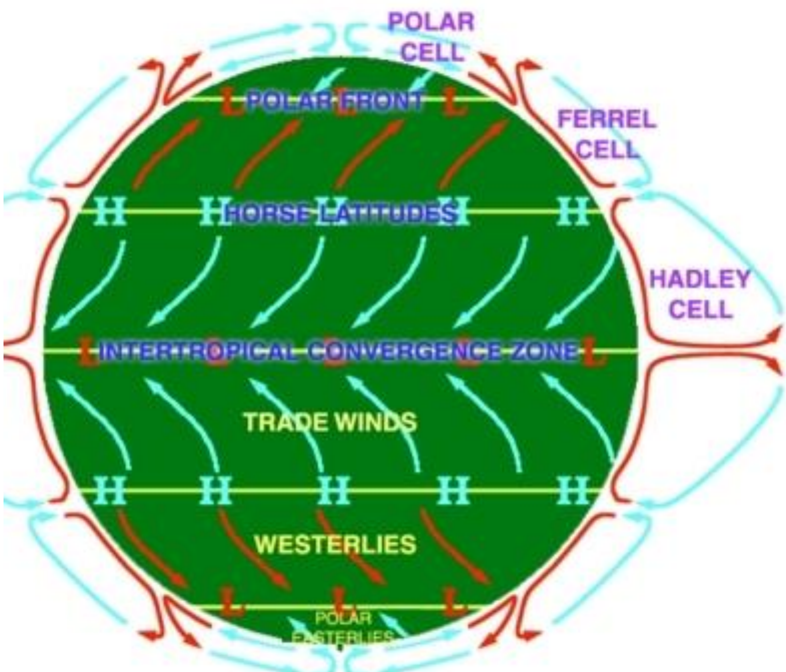
A surface weather analysis for the United States on October 21, 2006

Two Convection Cells

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense, and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator.

Coriolis Effect

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the **Coriolis effect (apparent deflection of a moving object because of earth's rotation)** must be taken into account.



The atmospheric circulation cells, showing direction of winds at Earth's surface.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the **Coriolis effect** (see Figure above). Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (In reality, it just appears to deflect to the right because the ground beneath it moves.) At about 30°N latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0° and 30°N.

Northern Hemisphere Convection Cells

There are two more convection cells in the Northern Hemisphere. The Ferrel cell is between 30°N and 50° to 60°N. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50°N to 60°N and the North Pole, where cold air descends.

Southern Hemisphere Convection Cells

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis effect makes objects appear to deflect to the left. The total number of atmospheric circulation cells around the globe is six.

Lesson Summary

- The atmosphere has six major convection cells, three in the northern hemisphere and three in the southern.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Coriolis effect make it so that global winds deflect to the right in the Northern Hemisphere and deflect to the left in the Southern Hemisphere.
- Winds blow at the base of the atmospheric convection cells.

Think Like a meteorologist

1. In what atmospheric layer does weather occur?

2. What creates low and high pressure zones?

3. What does air temperature have to do with precipitation?

4. Draw a diagram, label, and explain the north and south convection cells.

5. What is a Ferrel cell? Hadley cell?

Practice

Watch the following video and answer the questions that follow.

http://www.youtube.com/watch?v=DHrapzHPCSA

6. Where is insolation strongest?

7. What type of pressure occurs at the equator?

8. What type of pressure occurs at the poles?

9. What are Hadley cells?

10. Where does convection occur?

11. How do surface winds move?

12. Describe how air moves at high altitudes?

13. Diagram and label the parts of a convection cell in the troposphere.

14. How many major atmospheric convection cells would there be without Coriolis effect? Where would they be?

15. How does Coriolis effect atmospheric convection?