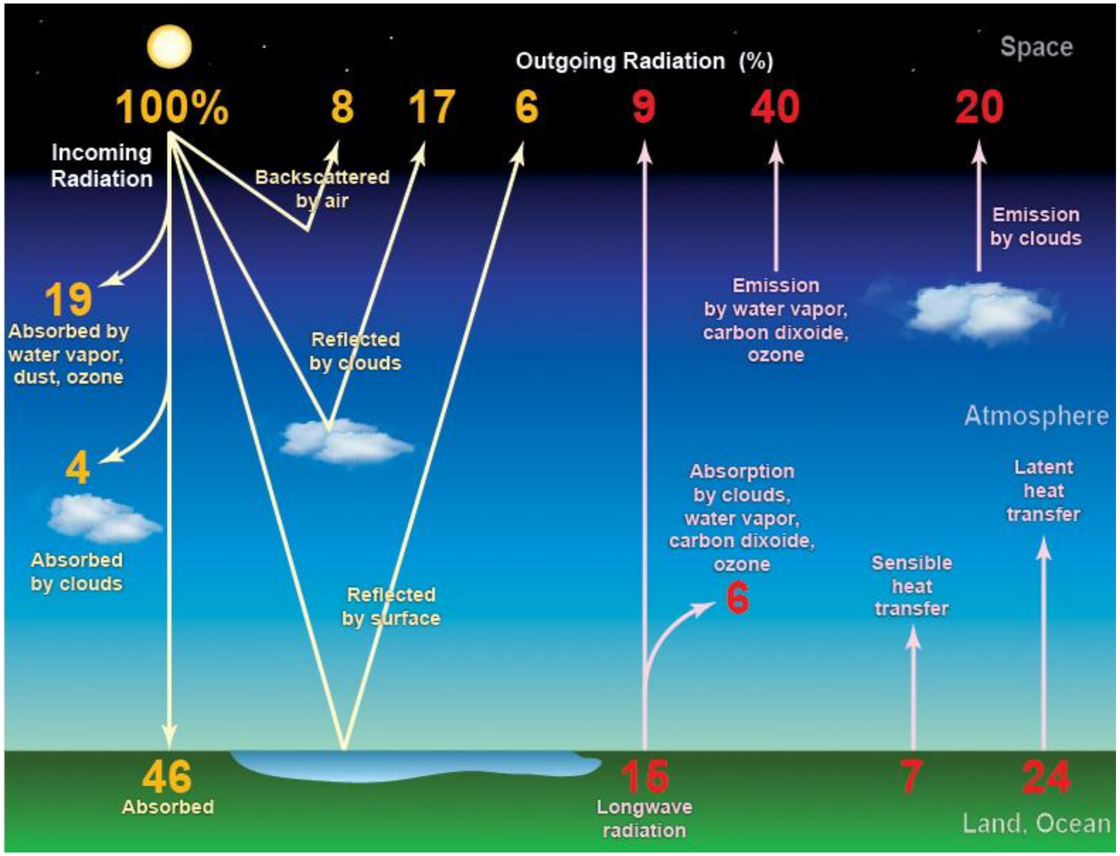
Planetary Energy Balance

Overview of Planetary Energy Balance

Energy coming into the Earth's atmosphere from the sun is always in balance with the energy leaving Earth's atmosphere going back out into space.



Solar energy is produced by nuclear fusion in the Sun and radiates towards Earth. The atmosphere, the clouds, and the Earth's surface absorb some of the energy and reflect some of it too.

Forms of Energy

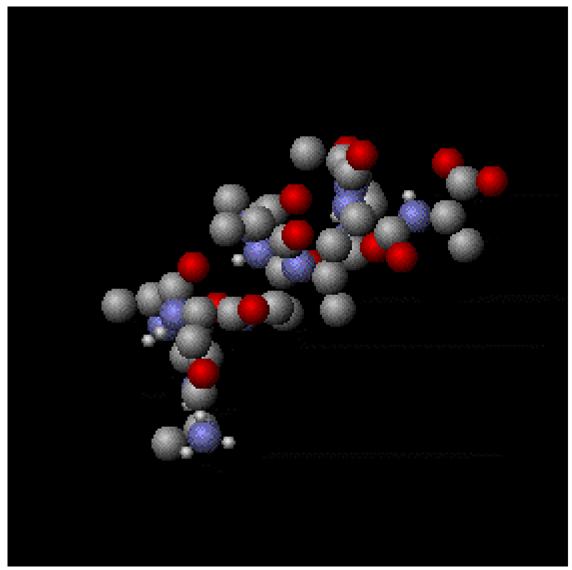
To understand how the planet balances energy, let's first discuss some basic definitions of energy. Energy is the "ability to do work" and comes in two general types: 1) kinetic energy, the energy of motion and 2) potential energy, which can be found in various forms.

KINETIC ENERGY

Kinetic energy is the work that can be done by moving masses, such as a hammer hitting a nail. The moving masses can be very small, such as the molecules of a solid, liquid, or gas.

THERMAL ENERGY

The kinetic energy involved in random motion of molecules is called ***heat***. Hotter objects have molecules that move faster, each carrying more energy. ***Thermal energy*** is really the collective kinetic energy of all the molecules in an object.



Heat Capacity

Different materials hold heat in different ways.

LARGE HEAT CAPACITY

Some materials can absorb lots of energy without a large temperature increase. These materials have a large heat capacity. Water has a very large heat capacity.

LOW HEAT CAPACITY

Some materials have a large temperature increase when they absorb energy. These materials have a low heat capacity. Rocks, soils, sand, and other land surface materials have a very low heat capacity.

DID YOU KNOW?

Since water has a large heat capacity, there are only small temperature differences between day and night in the ocean.

Sand has a low heat capacity, so in the desert there are large temperature differences between day and night.

Heat Transfer

Heat can be transferred from one object or parcel of fluid (liquid or gas) and moved to another location in a few different ways.

Conduction

Conduction is the transfer of molecular kinetic energy within a material or by direct contact of two (usually solid) objects. The heat moves (diffuses) along a thermal gradient from warmer to cooler temperatures until the temperature equilibrates. The molecules of one object collide with neighboring molecules and thus transfer kinetic energy, or heat.

Convection

Convection is the transfer of heat by the large-scale movement of a parcel of fluid (liquid or gas) from one place to another in a gravitational field, due to the fact that warmer fluids are less dense than cooler fluids. ("Hot air rises.") This moves heat by moving the material that carries it.

Radiation

Radiation is the transfer of energy by electromagnetic radiation of various wavelengths, including visible light, radio, x-rays, etc. Electromagnetic radiation is emitted by all objects, and the frequency (thus energy) depends on the temperature of the emitting object. The radiation is absorbed by another object thus raising its temperature.

DID YOU KNOW?

The terms advection can sometimes be confused with convection.

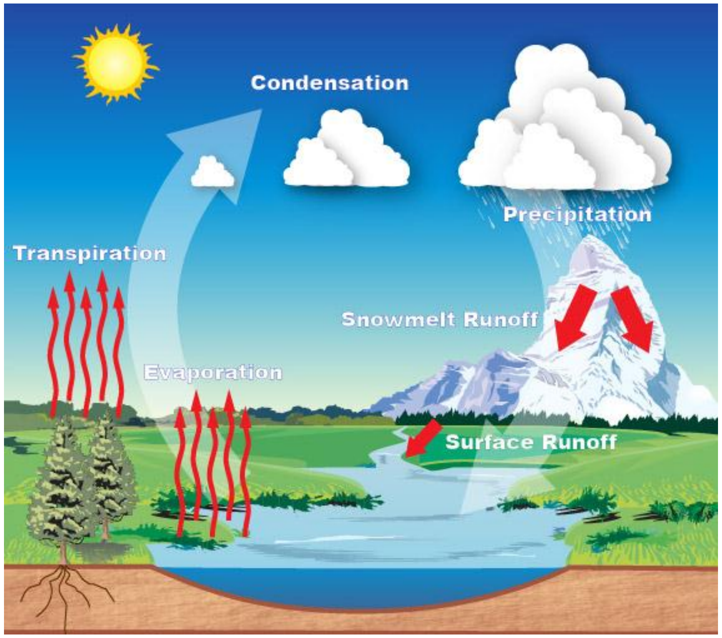
Advection is the transfer of heat by (typically) horizontal motion of fluid not directly involved in convective rise due to density differences.

Latent Heat

Energy, or latent heat, is transported around the atmosphere as water evaporates and condenses.

Energy is required to melt or evaporate a material. This is called latent heat of fusion (melting) or vaporization. When water is heated, it evaporates more rapidly than when it is cooled.

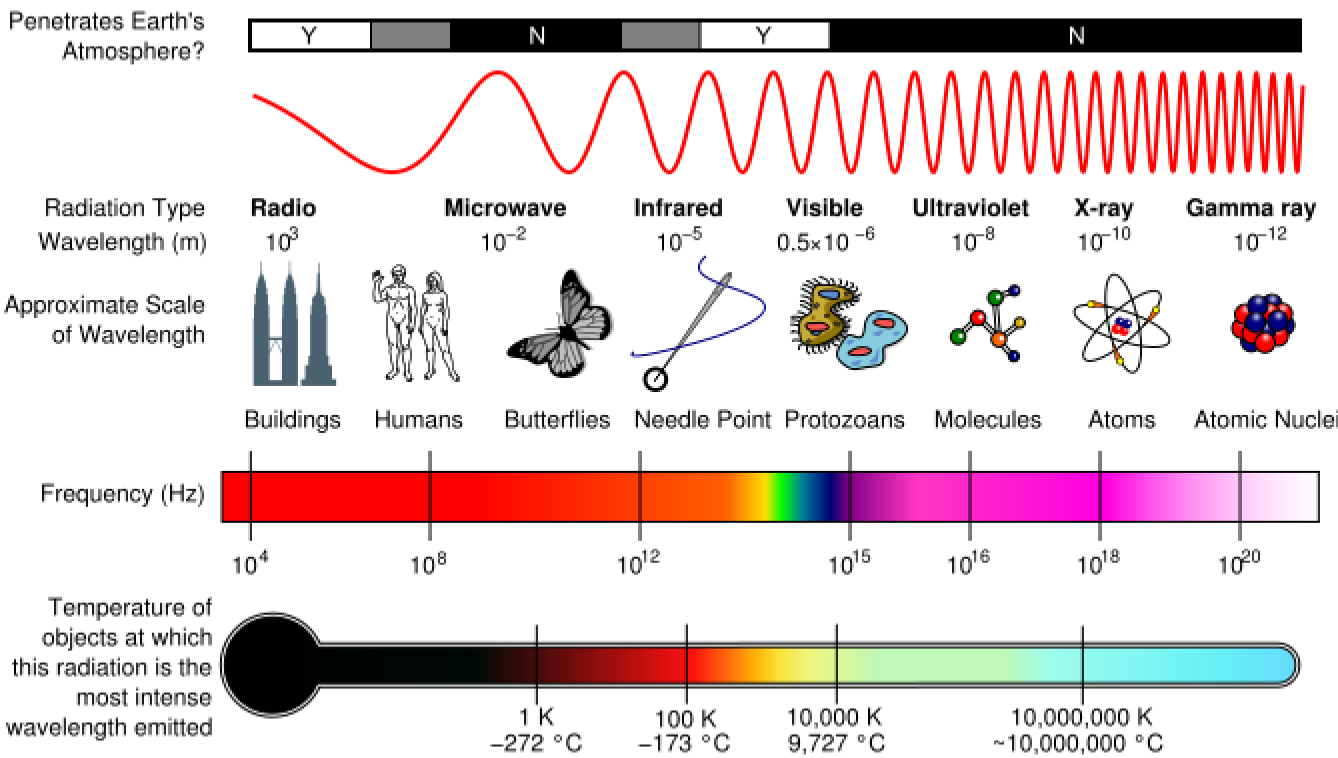
A material releases energy when it condenses or becomes a solid. This is called latent heat of condensation or crystallization. Clouds are an example of condensation in the atmosphere.



During evaporation, heat is added to change the state of water, for example, without changing temperature. Thus, evaporation cools the surface from which water evaporates, and provides latent heat to the atmosphere. This thermal energy is liberated when water condenses into droplets that may form clouds or rain, thus releasing the heat to the atmosphere.

Electromagnetic Spectrum

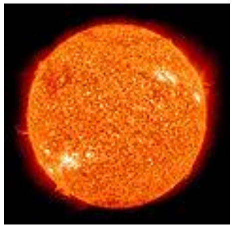
The electromagnetic (EM) spectrum includes long wavelength and low frequency radio waves on one end, and short wave lehgth high frequency gamma rays on the other, with visible light as a narrow band in the middle.



The wavelength determines the type of electromagnetic radiation—whether it's infrared, ultraviolet, or something else. Certain wavelengths can penetrate the Earth's atmosphere; others cannot. The earth maintains its energy balance by either absorbing electromagnetic radiation or re-radiating the energy back into space.

Black Body Radiation, Absorption, and Re-Radiation

Black body radiation is the electromagnetic waves given off by all matter.



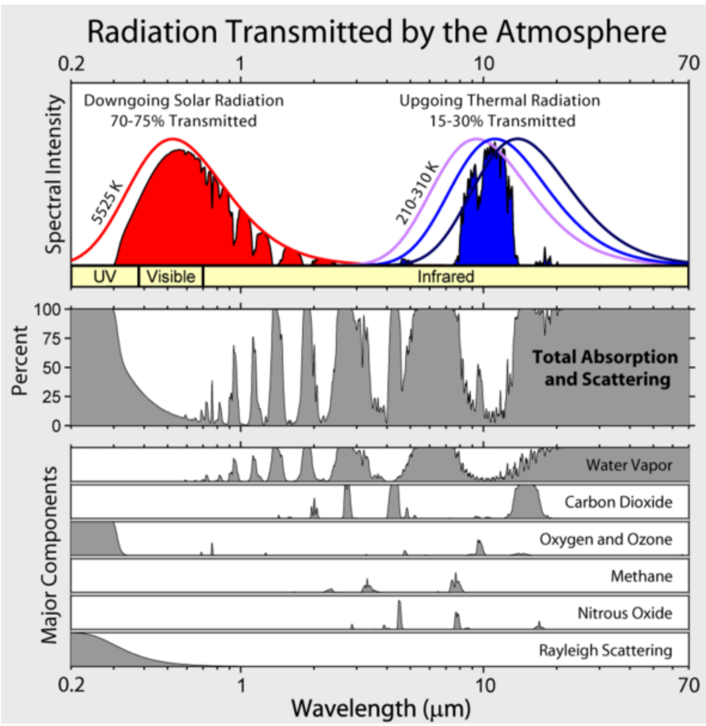
Hotter things radiate shorter wavelengths (higher energy) than cooler things. The sun radiates at about 6000 degrees C with an emission peak in visible wavelengths.

The earth absorbs the sun's radiation, becomes warm and re-radiates at a much cooler temperature of 15 degrees C, with an emissions peak in the infrared.

[IN THIS SPACE IS A VIDEO THAT CAN BE SEEN AT THIS LINK]
http://earthobservatory.nasa.gov/Experiments/PlanetEarthScience/GlobalWarming/GW_Movie1.php

Filtering and Chemical Effects in the Atmosphere

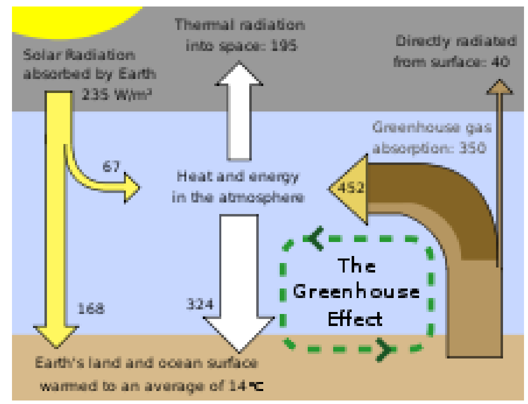
The atmosphere is not uniformly transparent to all wavelengths of electromagnetic radiation. The various gases absorb specific wavelengths by changing vibrational or rotational modes of molecules, or by breaking bonds that hold molecules together.



For example, the oxygen molecule (O2) is held together by a bond that has energy corresponding to high energy ultraviolet (UVC) wavelengths. Because there is so much O2 in the atmosphere (about 20%), virtually all UVC is absorbed by O2 before reaching the ground.

As another example, the third oxygen atom of ozone is held onto the other two O atoms more weakly, so this bond is broken when ozone absorbs a lower energy UVB photon. This is the essence of the problem of the stratospheric ozone hole, as UVB can damage cells and DNA of living organisms on the earth's surface.

Some gases absorb much lower energy (longer wavelength) EM radiation. The class of greenhouse gases, for example, absorbs the infrared radiation emitted by the earth's surface thus trapping it in the atmosphere.



Albedo Effect

Electromagnetic radiation that reaches the earth's surface can be absorbed or reflected, depending on the nature of the surface.

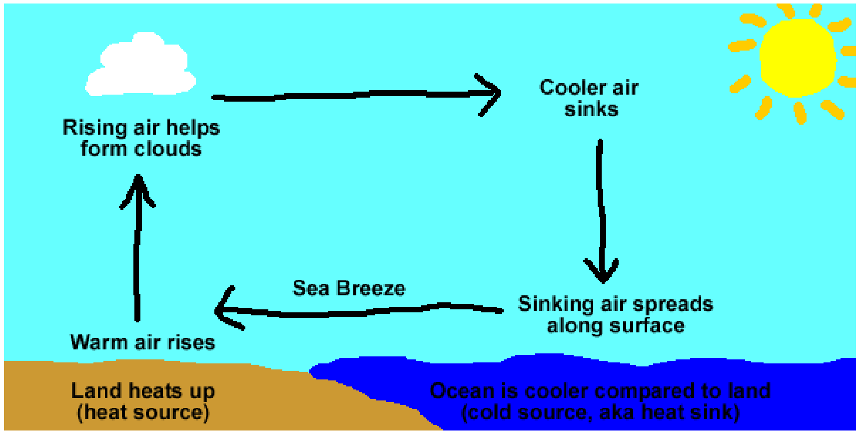
Dark colored surfaces absorb more of the incoming visible radiation. This is why macadam gets hot on a summer day, while the painted white lines do not. The darkest materials, with lowest albedo, include ocean water, and to a lesser extent plants such as trees.

Bright surfaces with highest albedo such as ice/snow, and to a lesser degree desert sand reflect most incoming radiation. Reflected radiation passes back through the atmosphere and into space without warming the earth.

Land and Water Effects

Water has a low albedo so absorbs heat under sunlight. Land absorbs less heat. However, water has a high heat capacity, so takes longer to warm than land.

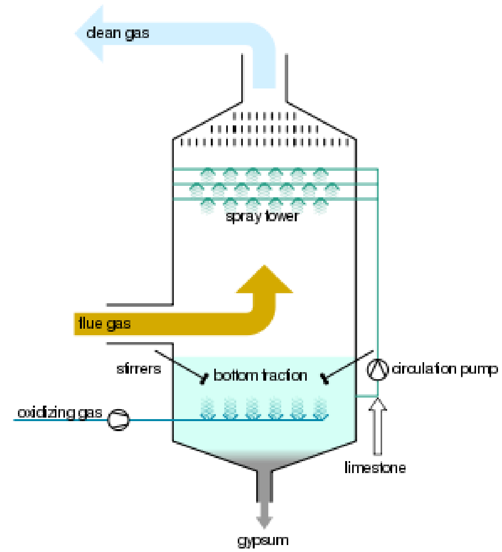
Due to land and water effects, summers can be very hot in continental interiors (and winters very cold), while marine climates are more moderate.



On a daily basis, land near the shore heats up in the afternoon so the overlying air rises, while the adjacent ocean is relatively cool. This causes air to move from the ocean to the land to take the place of rising heated air, thus creating a sea breeze.

Particulates in the Atmosphere

Liquid or solid particulates called aerosols can affect climate by altering the way electromagnetic energy flows through the atmosphere.



Particulates in the atmosphere can absorb and reflect various electromagnetic wavelengths. Where more particulates are present, like in smoggy urban areas, radiation is reflected and the region cools down. Where less particulates are present, more radiation is absorbed, so those regions heat up.

During the 1960's, there was intense emissions of sulfate and other aerosols into the atmosphere primarily from fossil fuel burning. Scientists observed a cooling effect on the bottom of the atmosphere near ground level. This led some to believe that the entire atmosphere was cooling because no measurements were available to observe any warming of the upper atmosphere at that time.

Since then, fuels have been burned more "cleanly" to reduce pollution and acid rain, and the surface cooling effect has been greatly reduced. For example, coal-fired power plants now have “scrubbers” which use calcium from limestone in the smokestack to convert sulfur dioxide into gypsum, a useful mineral used in wallboard.