Heating the Earth's Atmosphere

NWS

Science Partnership

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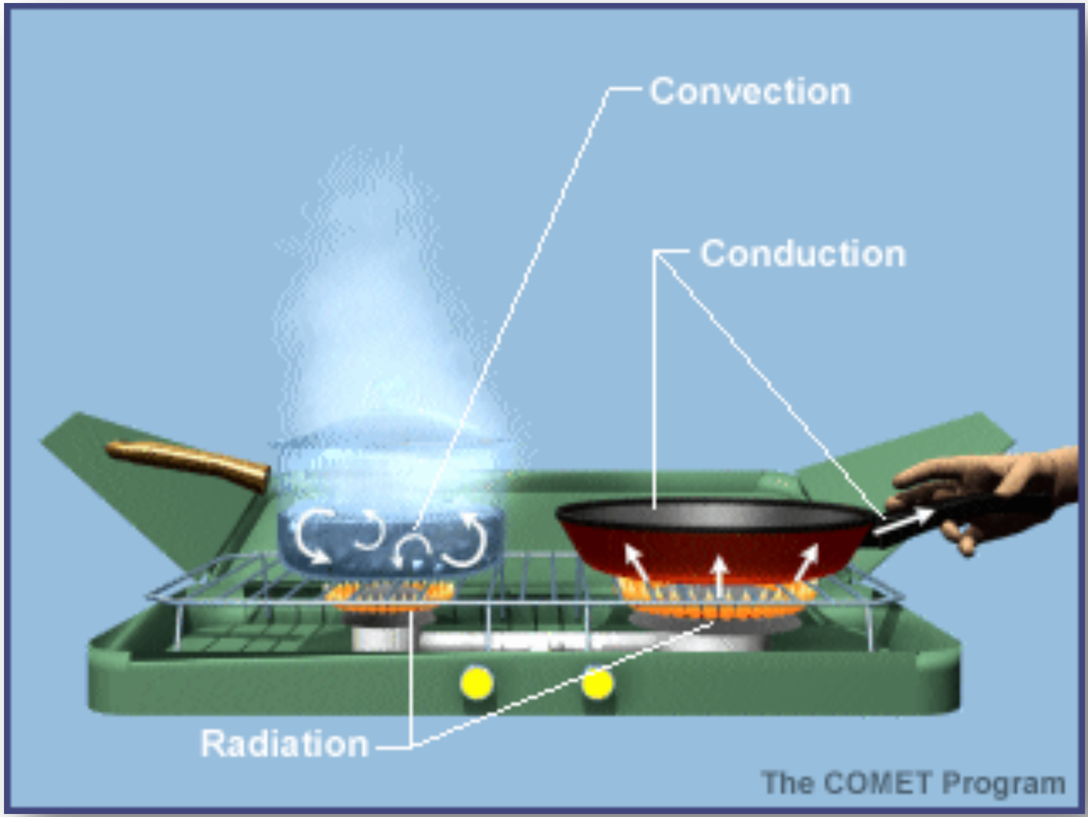
Heat Exchange Mechanisms (Heat Transfer)

There are several important heat transfer mechanisms that operate in the Earth system.



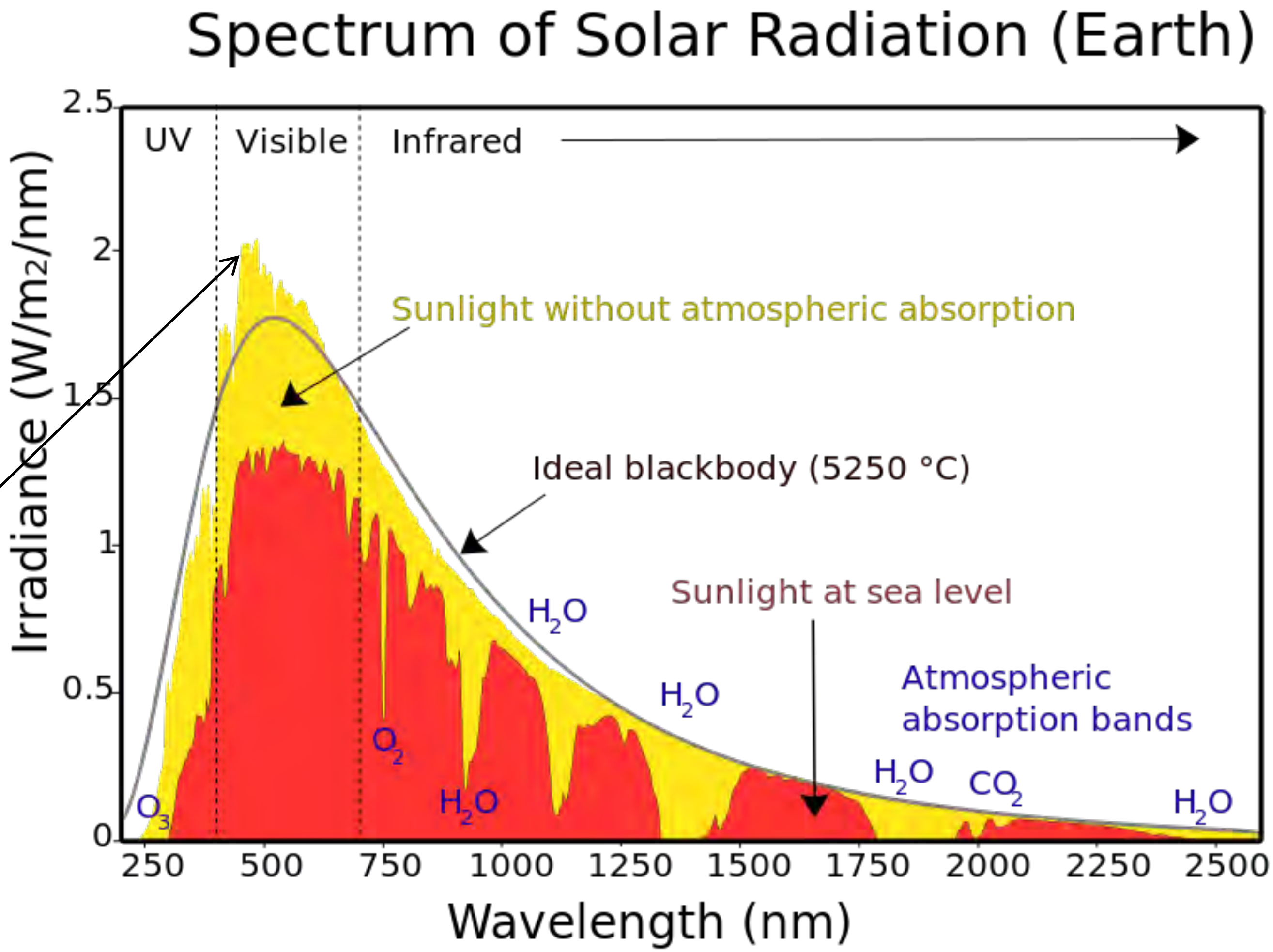
Conduction — transfer of heat from molecule to molecule within a substance. Heat transfer occurs from warmer to colder regions.

Radiation — heat transferred as electromagnetic radiation

Convection — transfer of heat by mass movement of fluid due to differences in buoyancy. Important for liquids and gases (generally not solids).

Advection — heat is transferred when matter is transferred from one place to another (winds and ocean currents).

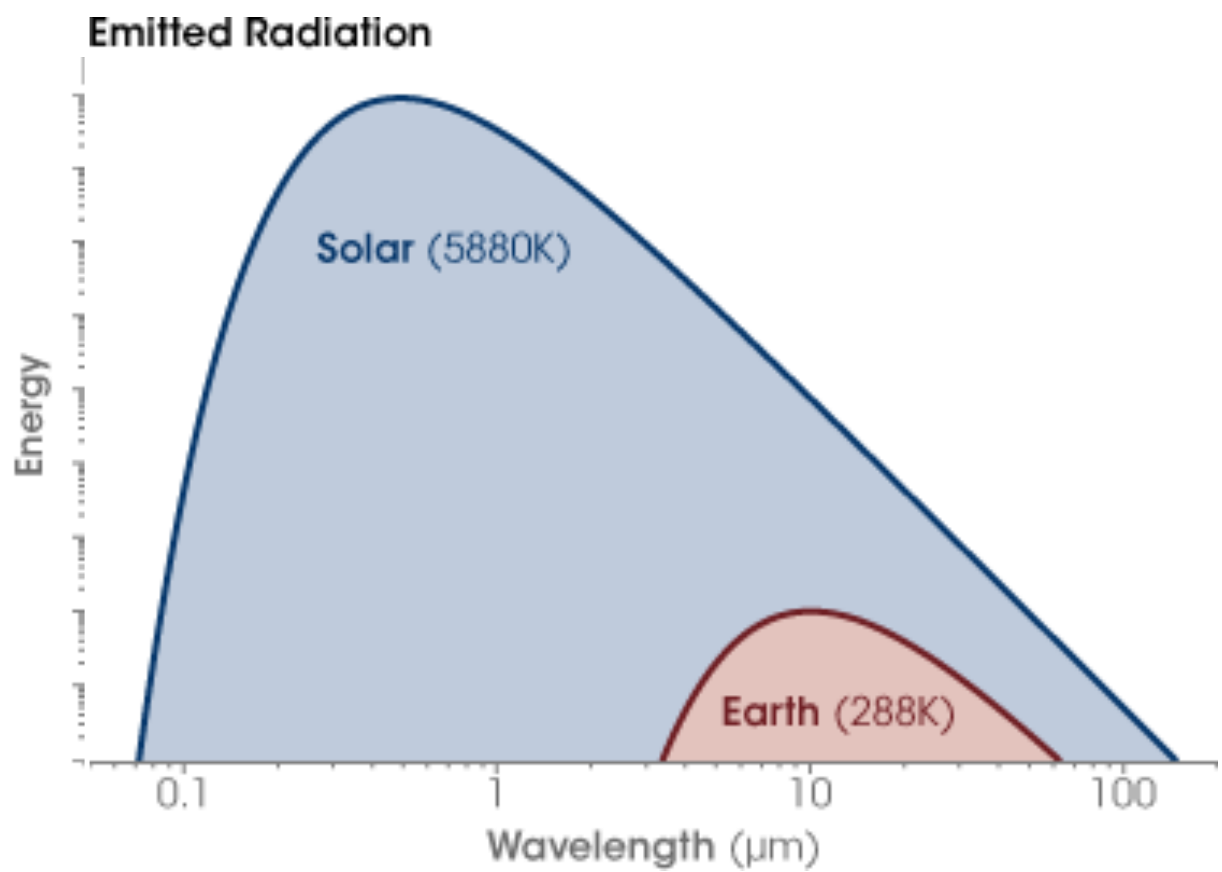
The Sun emits radiation at almost all wavelengths, but its maximum output is at relatively short wavelengths at about 500 nm wavelength in the visible region of the spectrum - green light.



The hotter Sun radiates more energy at shorter wavelength than the cooler Earth.

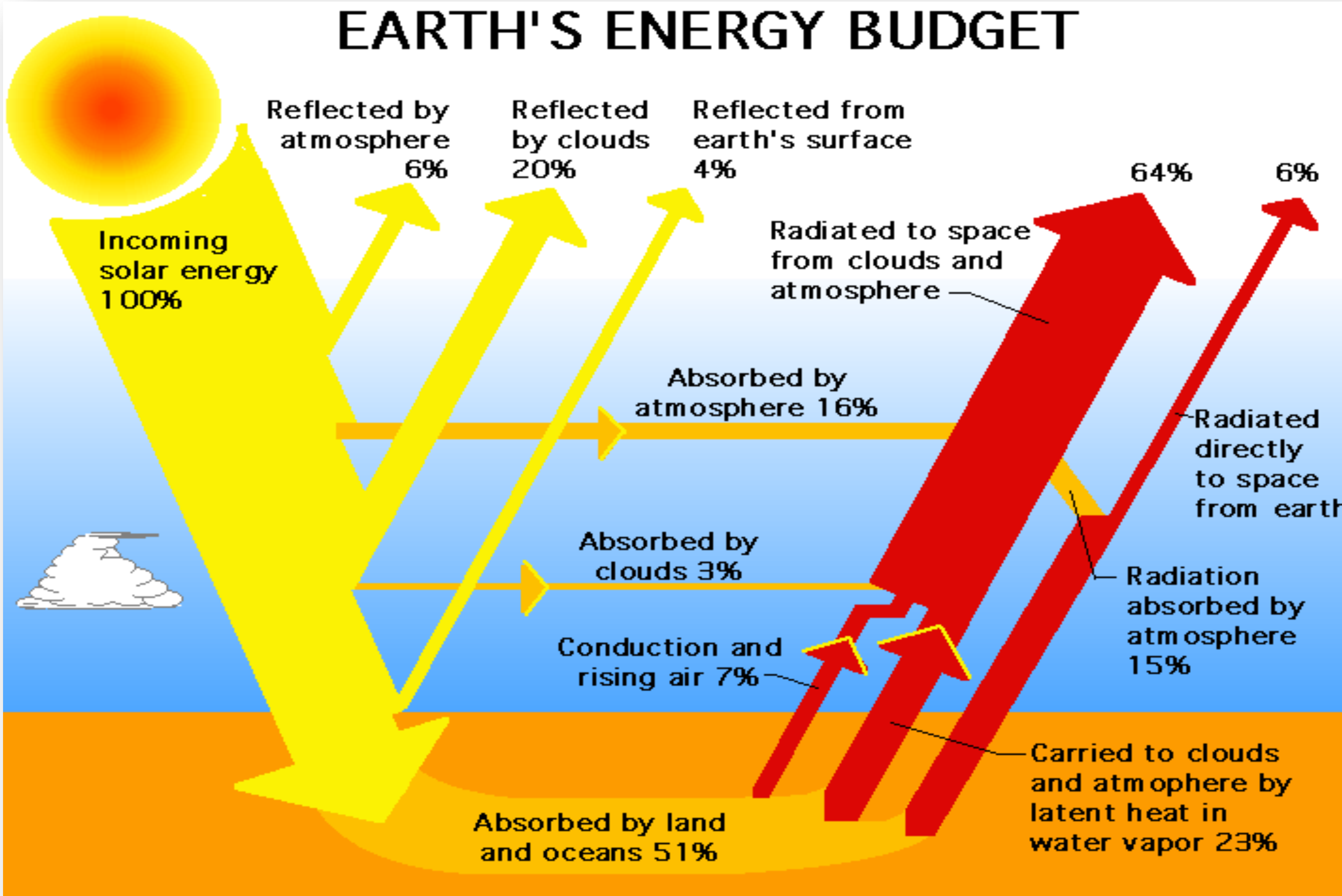
The left spectrum shows the solar output (in the visible region) and the right spectrum shows the Earth's emission that peaks in the longer wavelength infrared region.

The Earth radiates almost all of its energy between 5 and 25 mm.



NASA: Robert Simmon

The figure shows how different parts of the Earth absorb or reflect incoming solar radiation.



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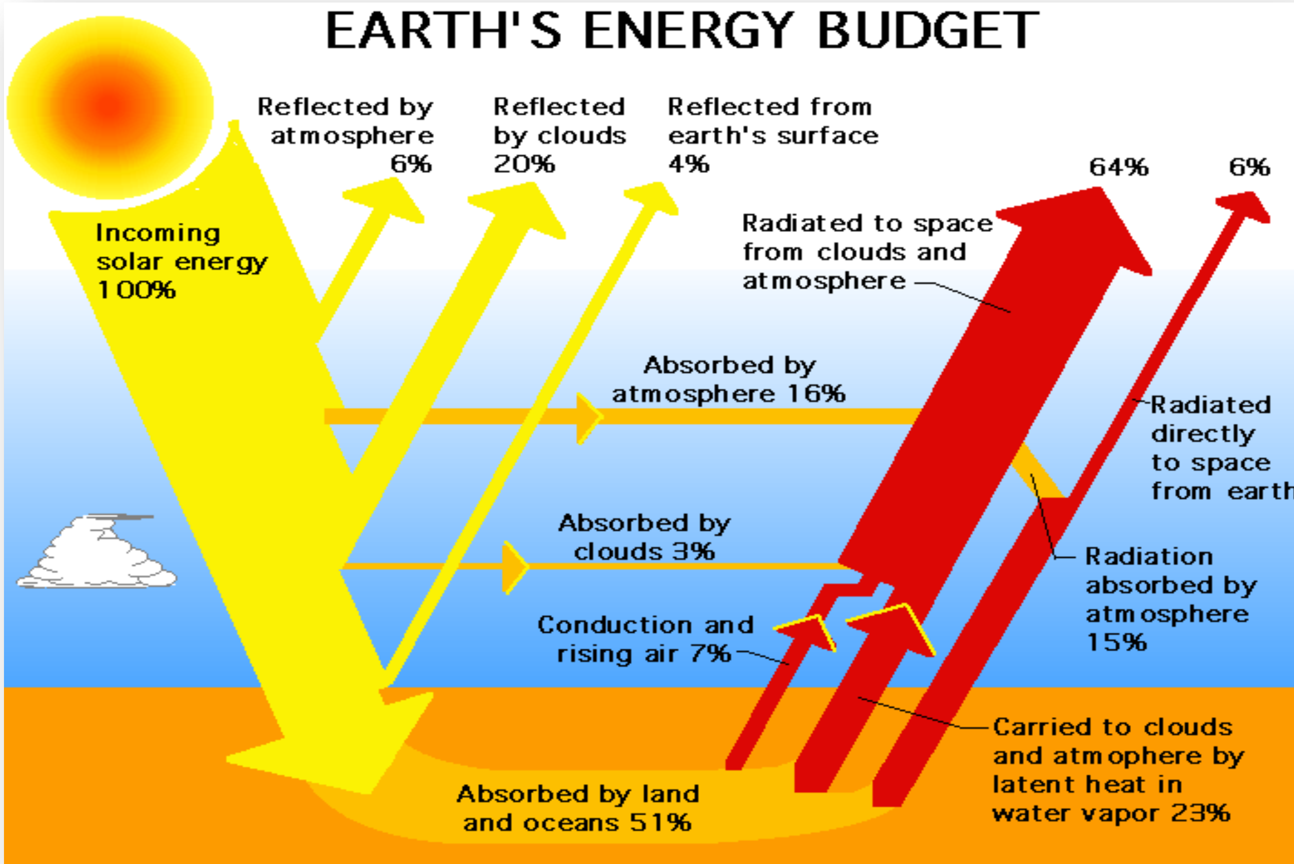
The Fate of Incoming Solar Radiation

Solar radiation strikes an object, it may interact in one of several different ways:



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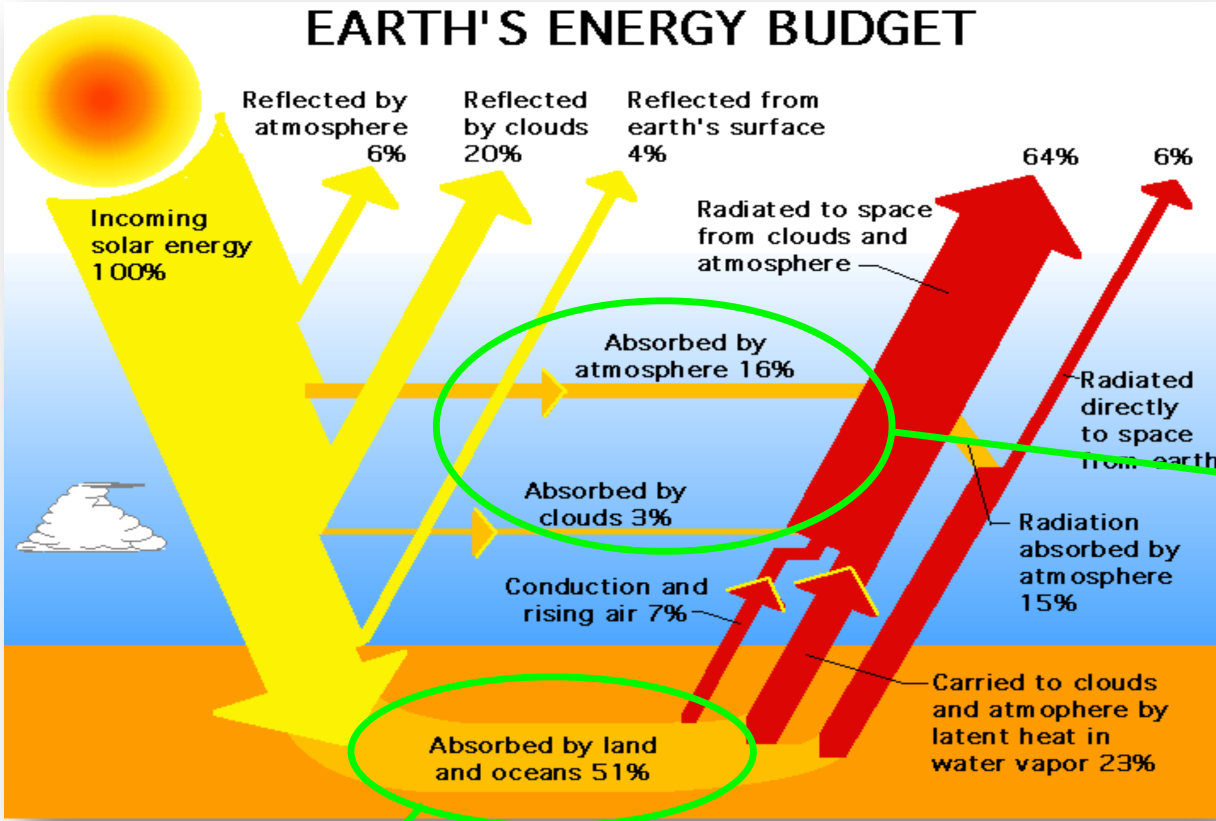
1. *Transmission* - some materials are transparent to specific wavelengths and pass (transmit) through the object/material without absorption.

The Fate of Incoming Solar Radiation



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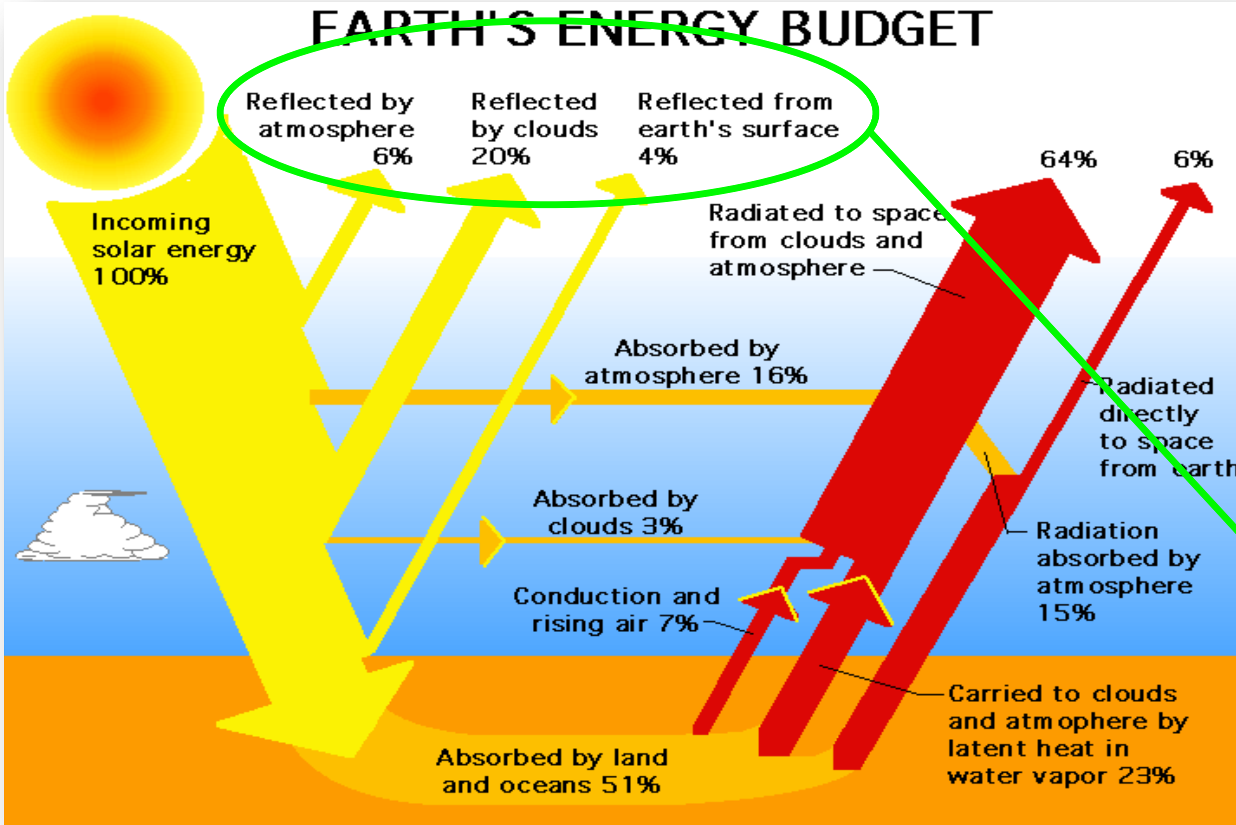
2. *Absorption* - solar radiation is absorbed, converted to heat and results in an increase in temperature.

~19% of solar radiation is absorbed by the Earth's atmosphere and clouds (mostly shorter wavelengths such as UV).

Visible light reaches the Earth's surface relatively unattenuated.

~51% of incoming radiation is absorbed by the Earth's surface (land and ocean).

The Fate of Incoming Solar Radiation



NASA

3. Radiation may "bounce off" the object without being absorbed or transmitted through *reflection* (and *scattering*).

~30% of solar radiation is reflected by the Earth's atmosphere, clouds and surface.

Reflection is when light bounces off an object. *Reflection* differs from *scattering* in that reflection of light is sent backwards (rather than in all directions).

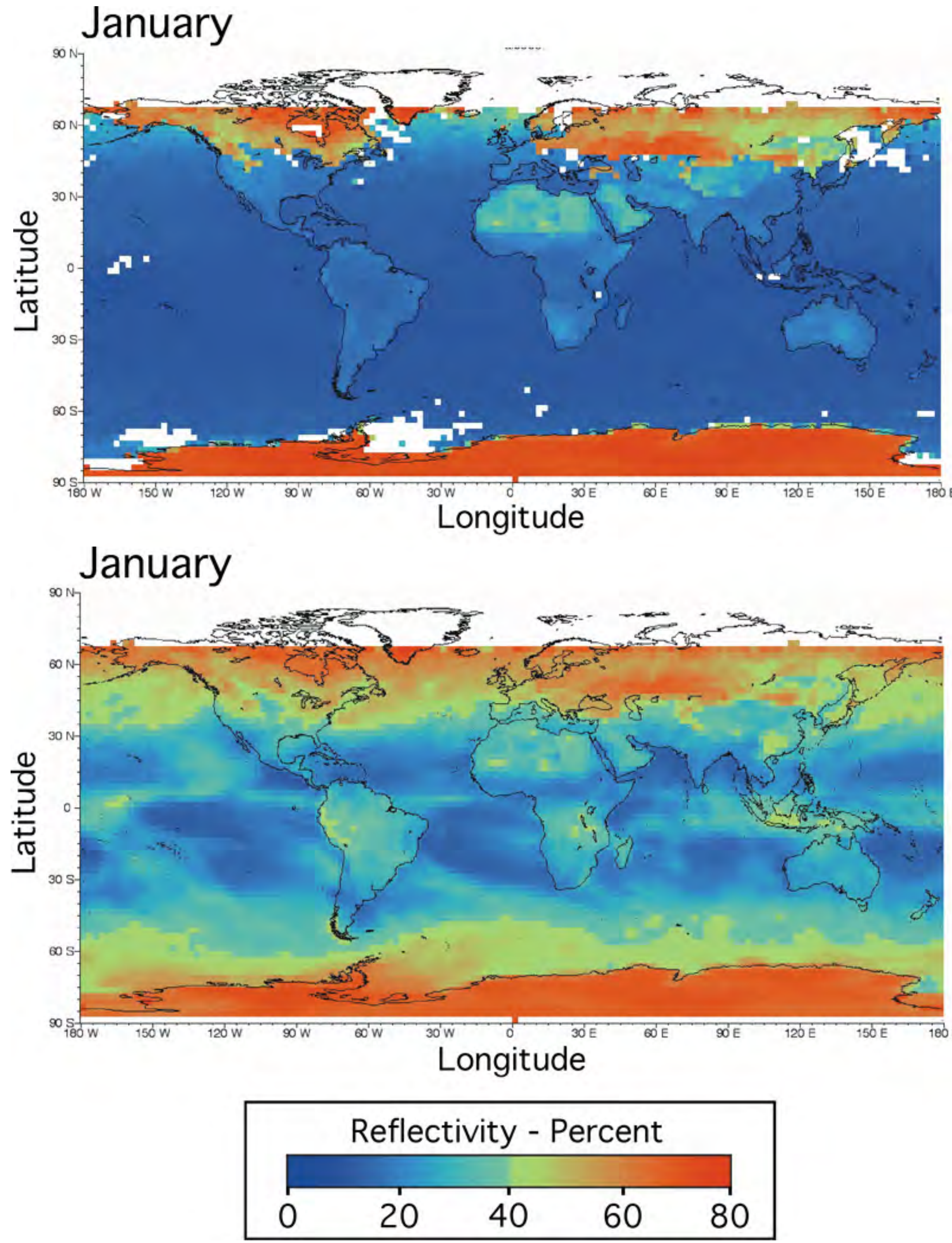
Albedo is the percent radiation that is bounced from a surface compared to the amount of light initially striking the surface - aka *reflectivity*.

Surface	**Albedo (%)**
Asphalt	5-10
Sand (white)	30-60
Soil (dark)	5-15
Soil (light)	25-30
Snow	80-90
Forest	5-10
Water	~8

NCSU Climate Education for K-12

The top figure shows the albedo (reflectivity) of the Earth's surface (January 1987). Note the low reflectivity of the ocean surface and the high reflectivity of the ice and snow surfaces at high latitude.

The bottom image shows the atmospheric and surface reflectivity. Note the higher reflectivity over the ocean surface due to clouds in the atmosphere.



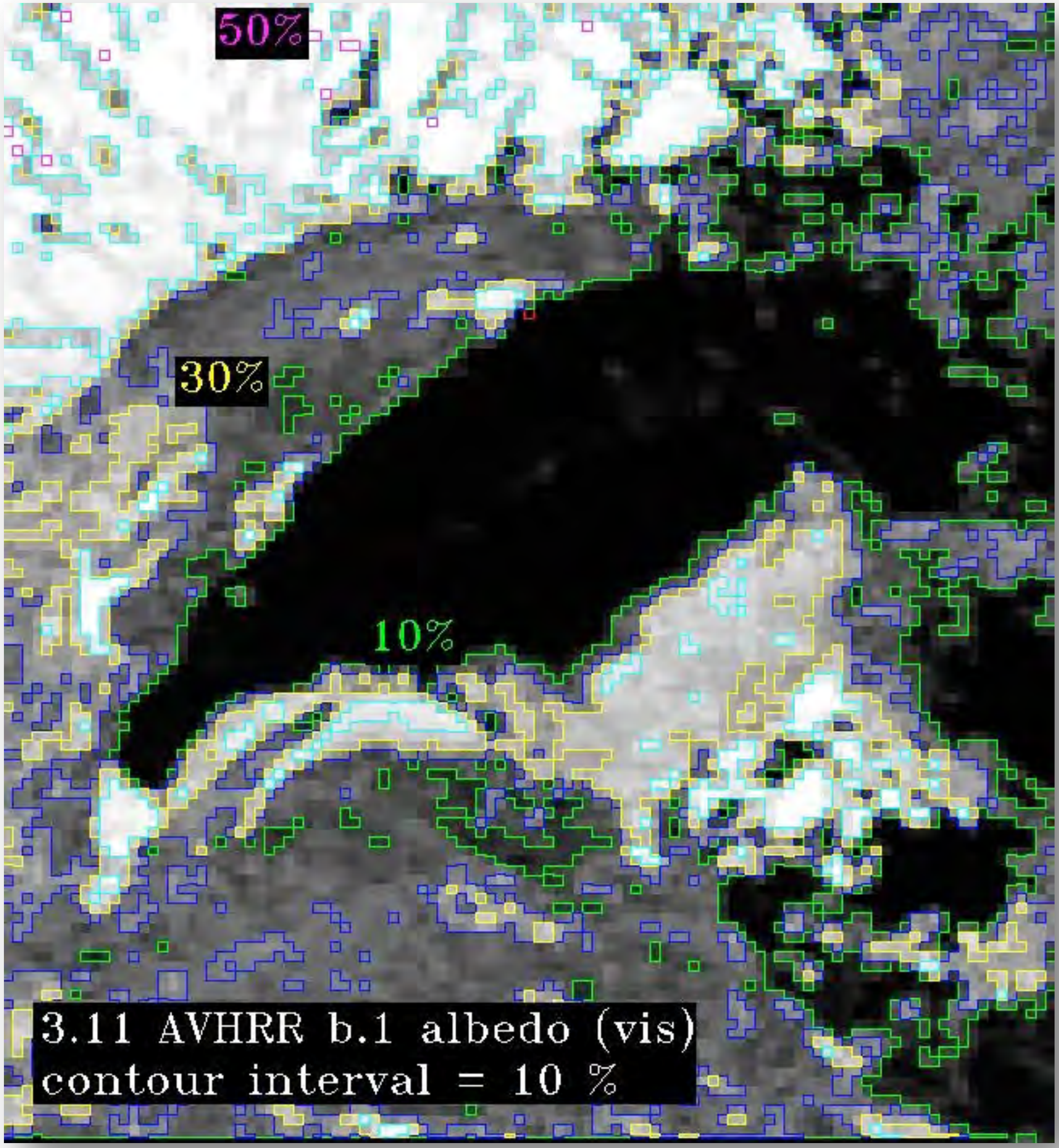
NASA Earth Radiation Budget Experiment

The figure on the right shows a image of Lake Superior contoured for albedo.

The lake appears dark and has an albedo of <10%.

The Earth's rocky surface has an intermediate albedo of ~30%.

The snow- and ice-covered regions have albedos of >50%.

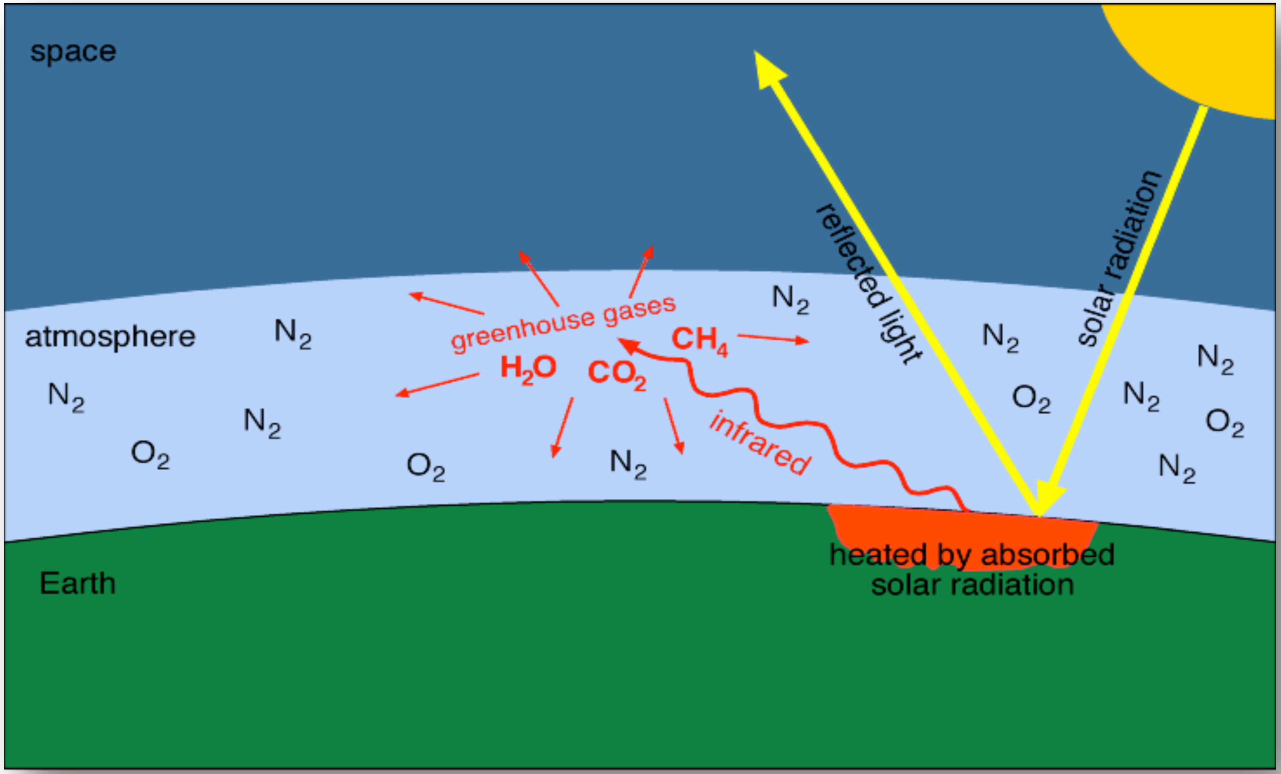


NOAA AVHRR

The Earth has an average albedo of ~30%.

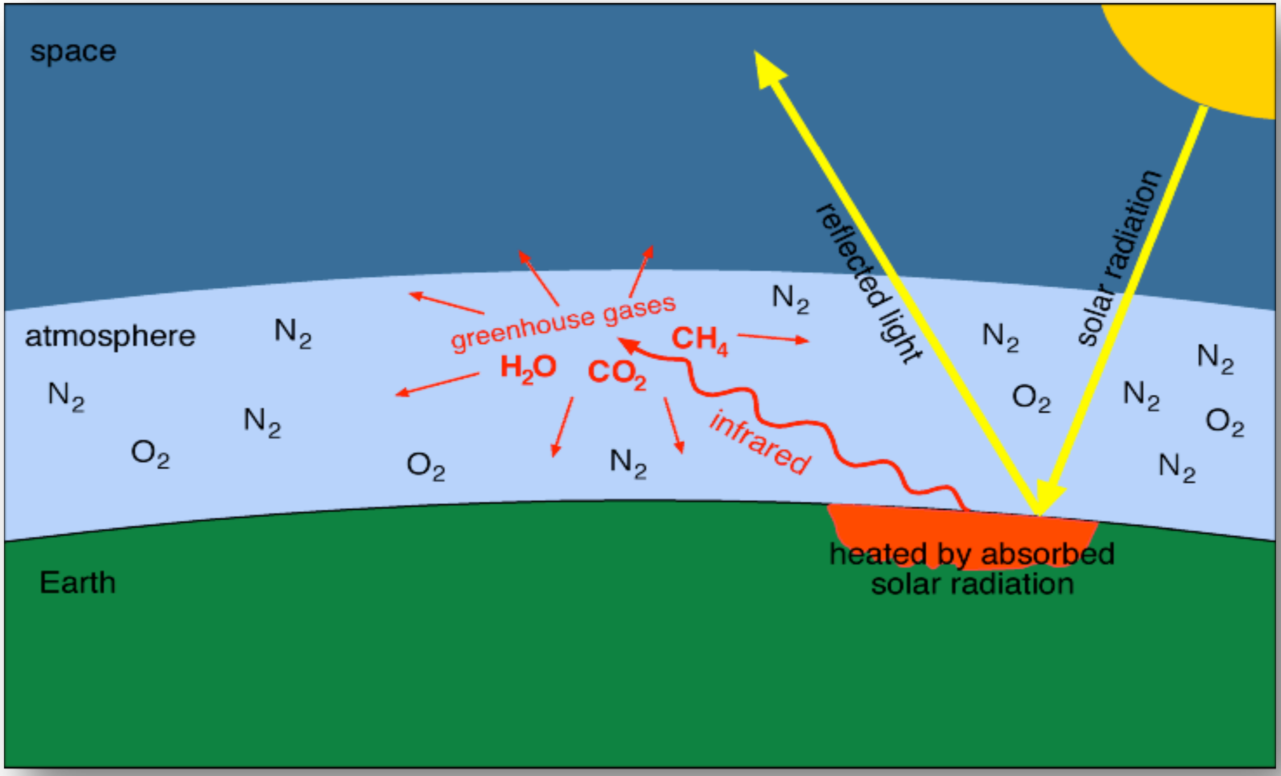
Heating the Atmosphere: The Greenhouse Effect

The Sun radiates most of its energy as short wavelength visible light which is absorbed by the Earth's surface (~51%). Absorption of the energy heats the Earth's surface. The Earth's surface then reradiates longer wavelength infrared radiation.



Columbia University: Vic DiVenere

Gas molecules in the atmosphere are transparent to the incoming shorter wavelength solar radiation and most of it passes through the atmosphere without being absorbed.

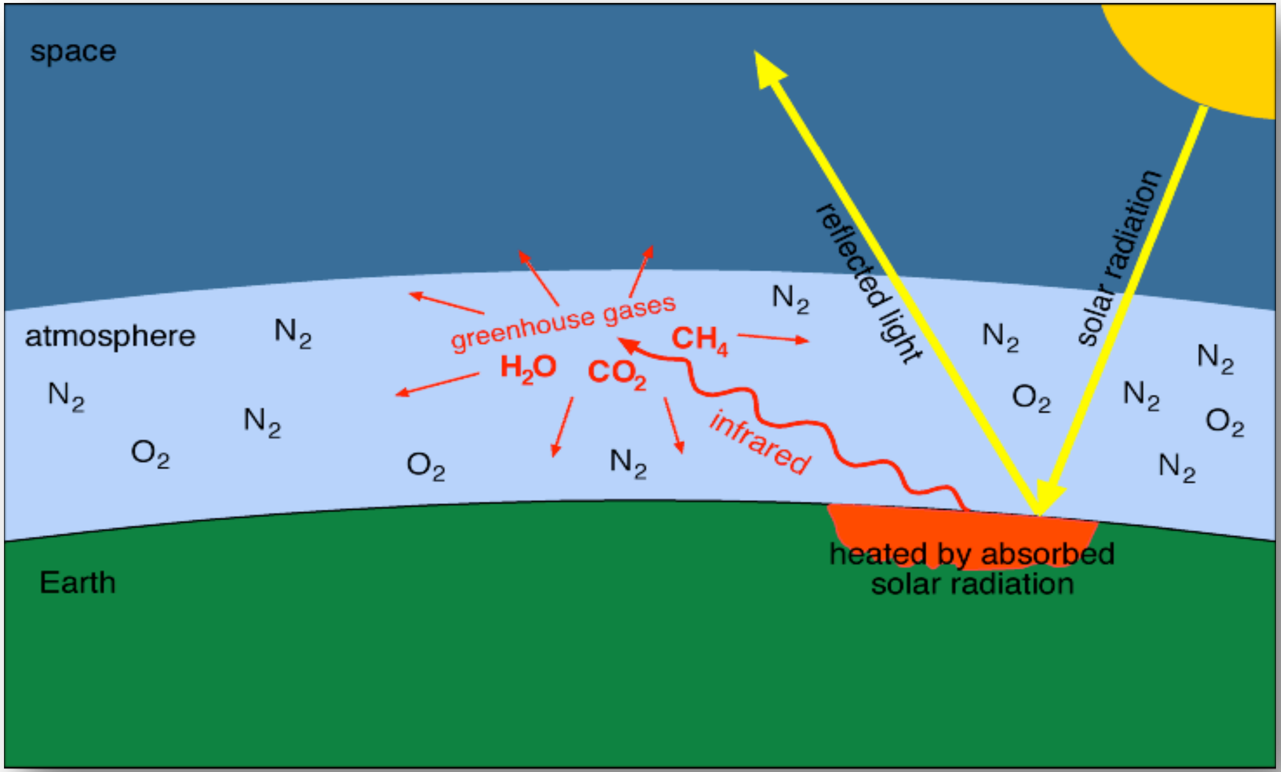


Columbia University: Vic DiVenere

H_2O and CO_2 molecules are absorb longer wavelength infrared radiation radiated by the Earth' surface.

The Earth's atmosphere is heated from the bottom up.

The heating of the atmosphere by the Earth's surface is known as the greenhouse effect - it keeps the Earth up to 15°C warmer than it would be without the greenhouse effect.

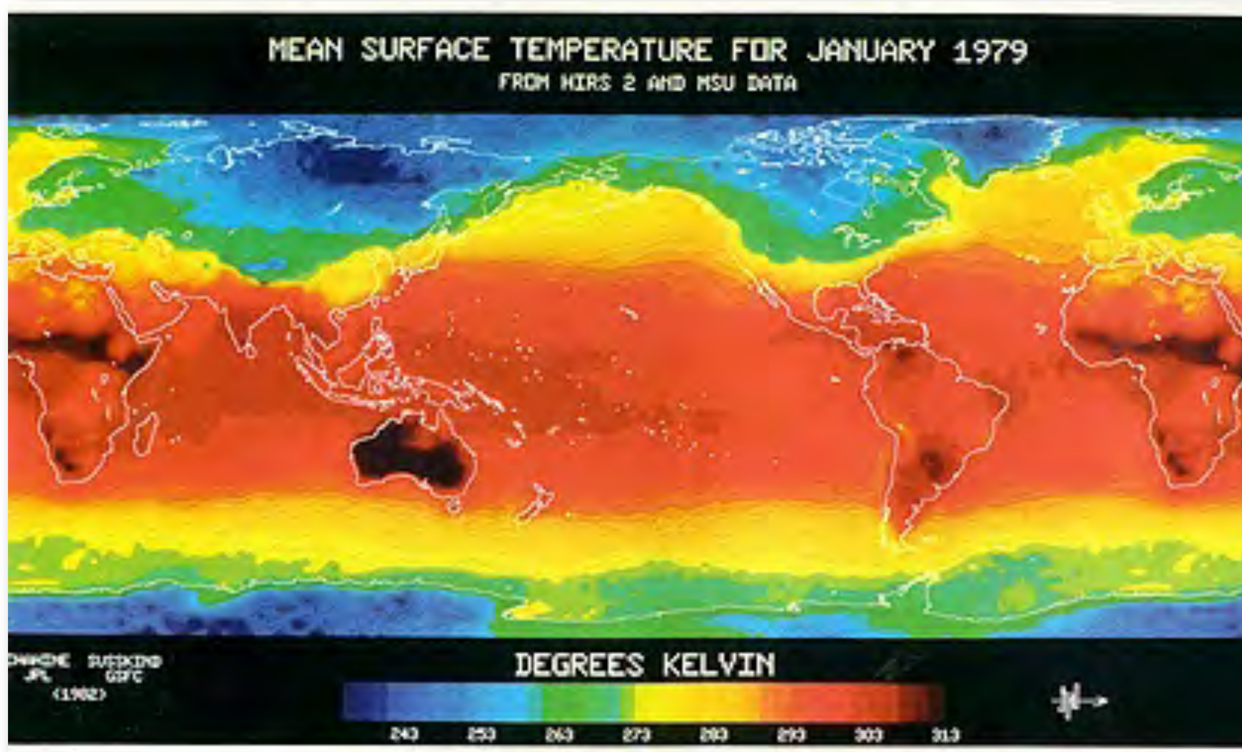


Columbia University: Vic DiVenere

Differential Heating of Earth's Surface

Even though the continents and oceans may receive the same amount of sunlight, they heat at different rates.

The image shows the Earth's surface temperature in January (winter in the northern hemisphere).



Note that adjacent continents and oceans have different temperatures.

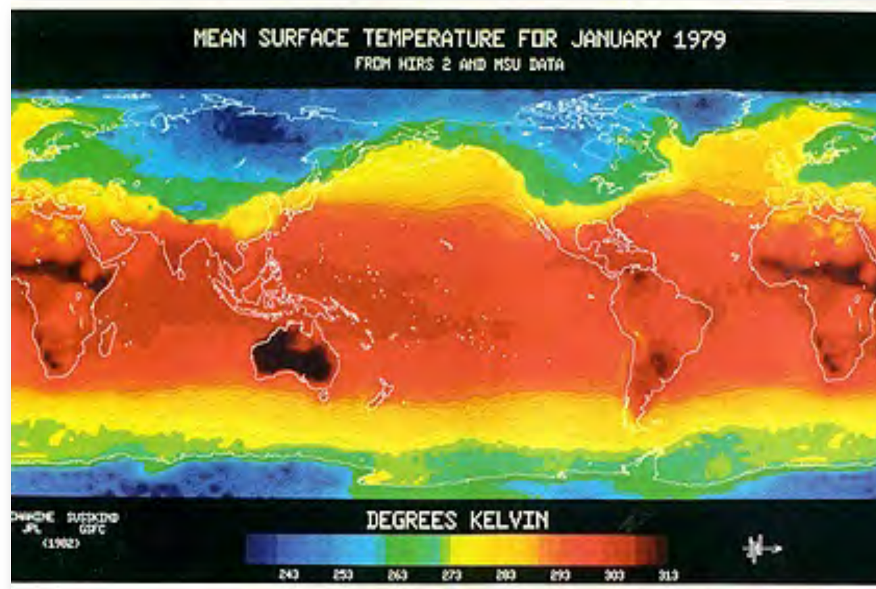
We know that different surfaces heat at different rates - would you rather walk barefoot on asphalt or grass on a hot day?

In general, soil and rock heat up and cool off more quickly than does water (heat capacity).

The reason that different substances heat up or cool off at different rates is due to a property know as the *specific heat capacity* of a substance.

Specific heat capacity, also known as *specific heat* is the measure of the heat energy required to raise the temperature of one gram of a substance by 1 K (or 1°C).

Substance	Specific Heat Capacity
Dry Soil	0.80 J/(g·K)
Dry Sand	0.83 J/(g·K)
Granite	0.79 J/g·K)
Water (25°C)	4.18 J/(g·K)



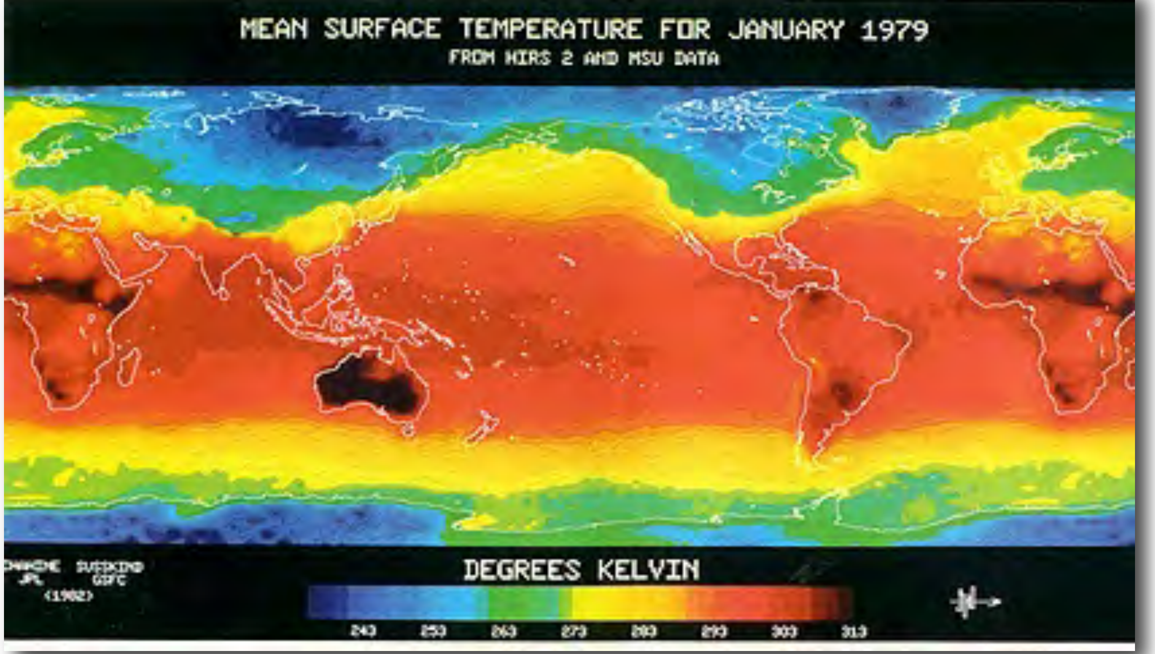
Note that water has a specific heat capacity that is more than 4x that of land surface materials. That means that it takes more than 4x as much energy to raise the temperature of water by one degree.

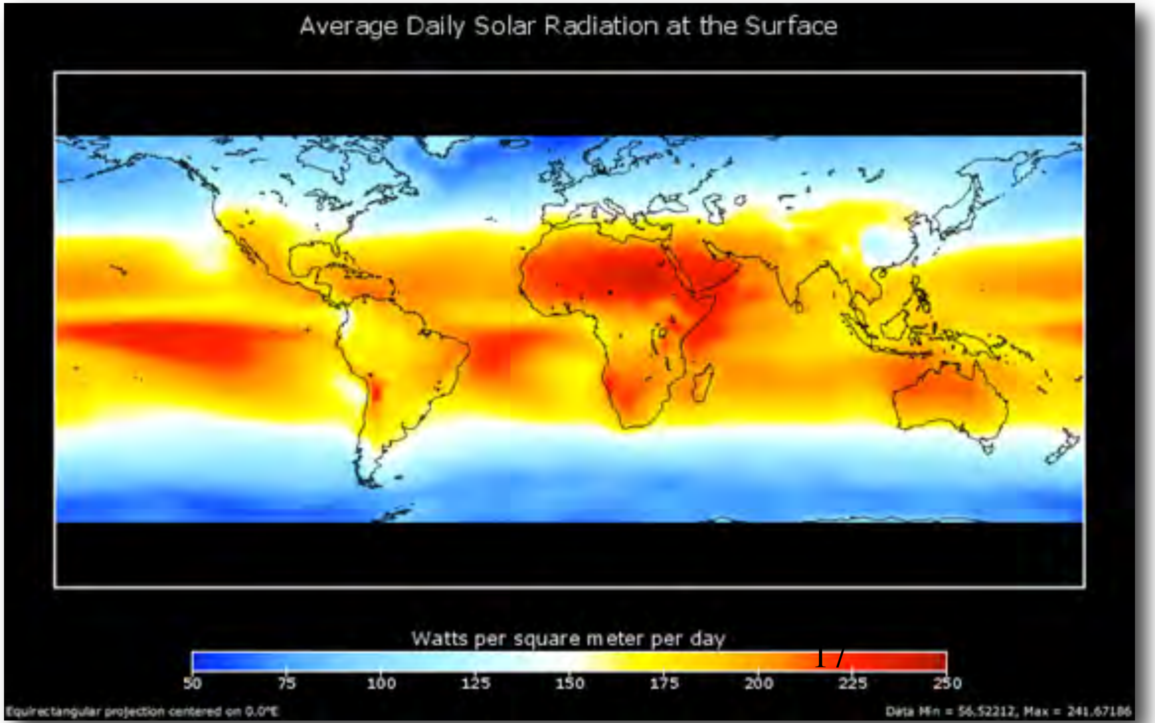
Sand and water absorb heat (energy) at approximately the rate, the difference is the response of the material as measured by temperature.

Solar Insolation

Another observation that can be made about the top map is that polar regions are colder. This not due to differential heating of surface materials but is due to the amount of solar radiation that can reach the Earth surface.

The bottom image shows the average amount of solar radiation reaching the Earth's surface. Note that this is strongly controlled by latitude.





Simple Example: Sea breezes are due to the differential heating of land and water.

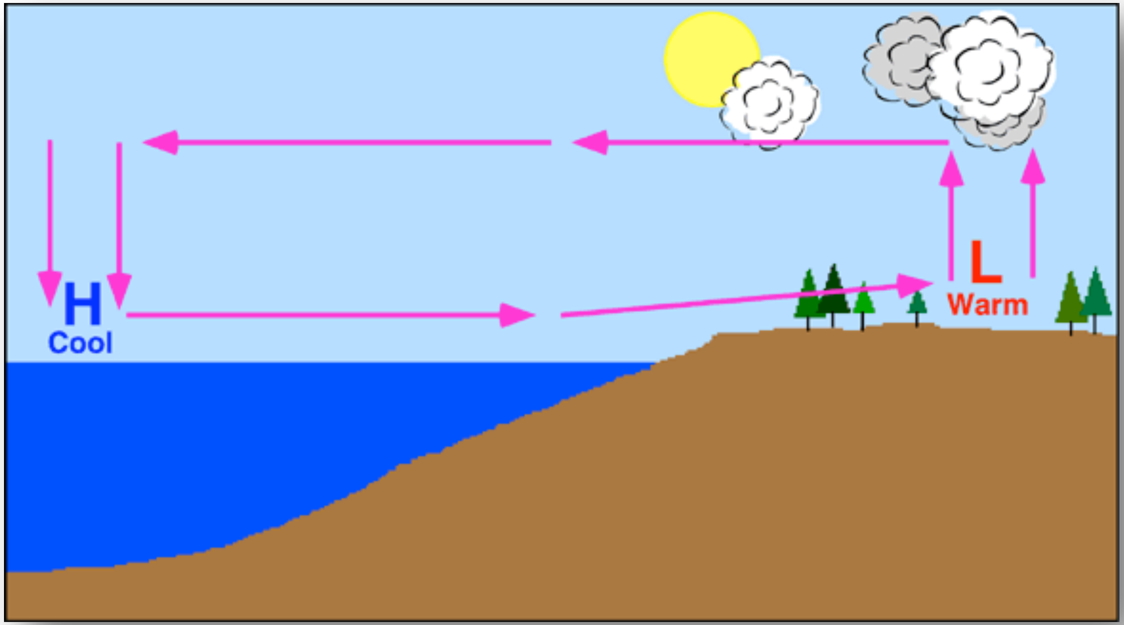
During the day, the land surface heats the lower atmosphere and the air begins to rise (updraft). Cooler sea air moves inland to replace the upward moving air.

A *sea breeze* is a type of *thermal circulation*. It is the *differential* heating rates of land and water that causes these local winds.

The *sea breeze* blows from the sea toward the land. The strongest winds occur at the beach.

Since the strongest thermal gradient occurs late in the afternoon, the *sea breeze* is strongest then.

The ascending air may result in cloud formation and thunderstorms.



physicalgeography.net Michael Pidwirny & Scott Jones

This Space Shuttle image shows the development of clouds over the land surface of Florida caused by *sea breeze* circulation cells.

Florida is subject to a lot of thunderstorms during the afternoon because the sea breezes from the Gulf and Atlantic can converge over the peninsula leading to atmospheric instability.

NASA

Another example: Land breezes occur because of the differential cooling of land and water.

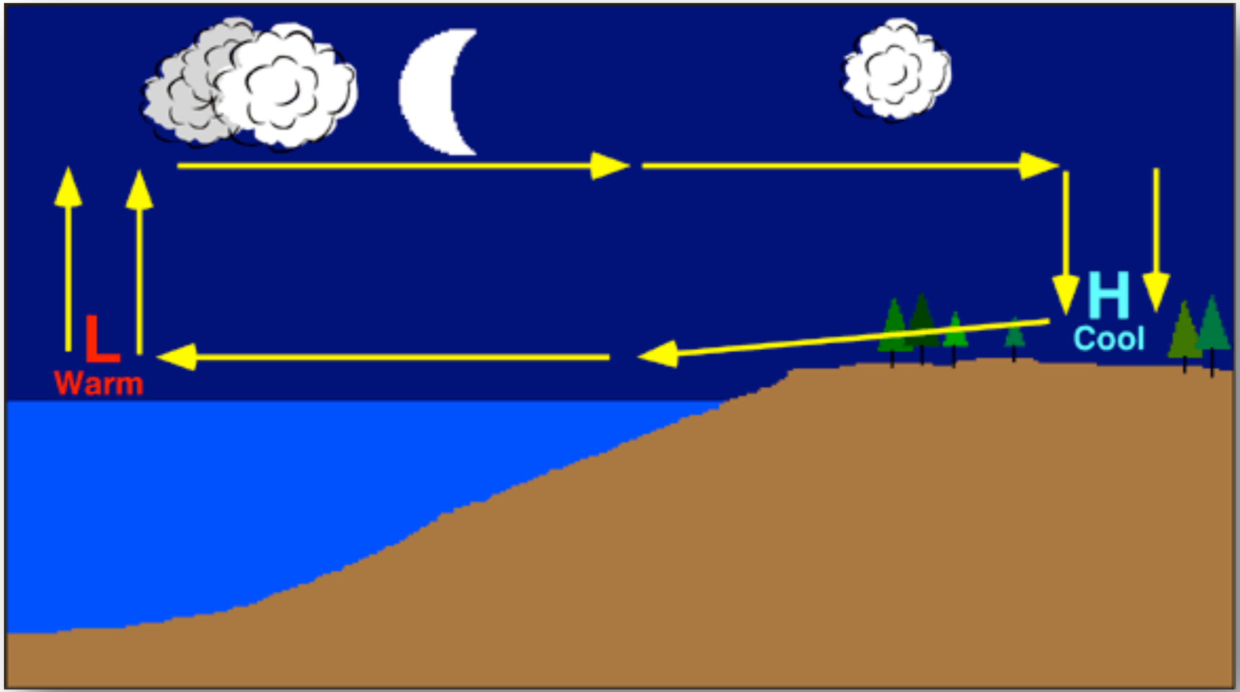
At night, the land cools more quickly than the water.

The warmest air at the surface of the Earth is over the water and it will begin to rise buoyantly

The sea breeze reverses itself and becomes a *land breeze* — flow from the land to the water.

In the region of ascending air, cloud formation is common.

On the east coast, it is common to have clouds over the land during the day and over the ocean at night.



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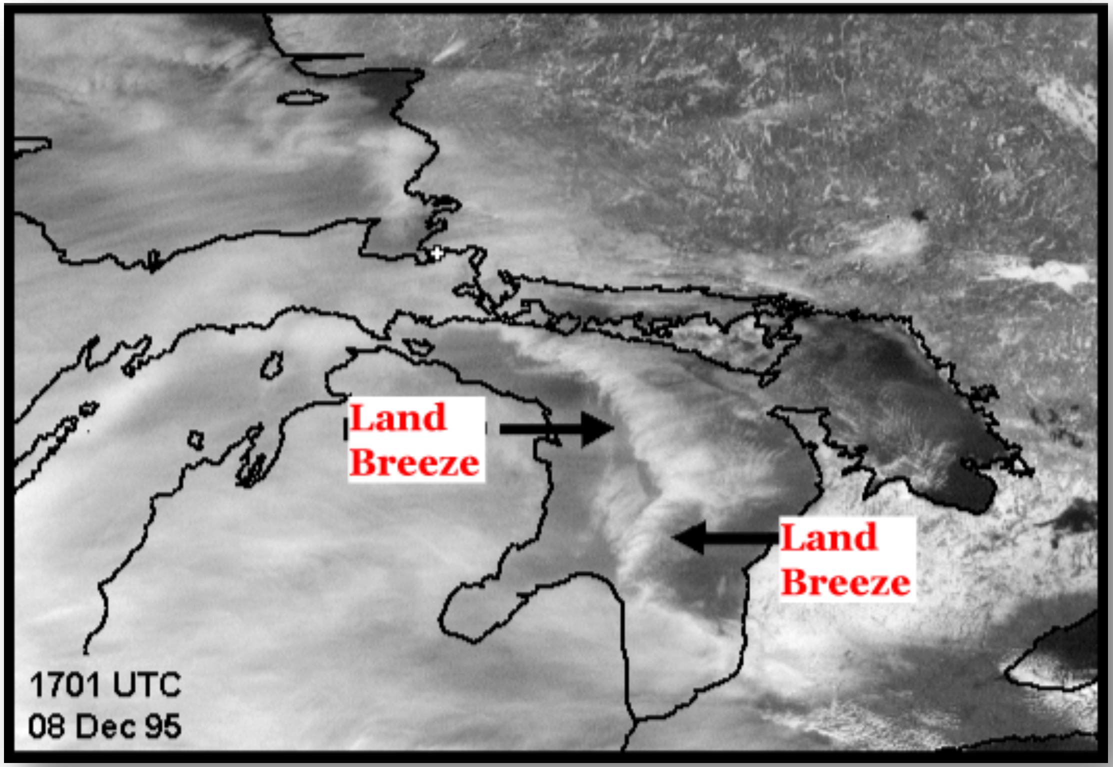
The image on the right shows the development of clouds over Lake Huron as the result of a *land breeze*.



The clouds develop in the region of ascending air associated with the *land breeze* circulation cell.

The image on the left shows towering cumulus clouds off the east coast of Florida shortly after sunrise. Cloud development associated with *land breezes* may become strong thunderstorms if there is even more lift and/or instability.