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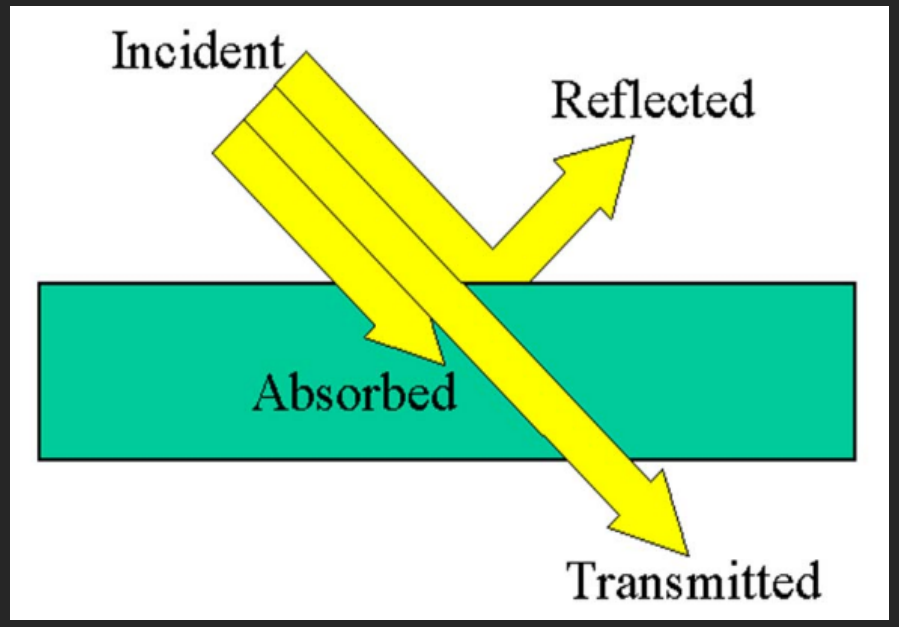

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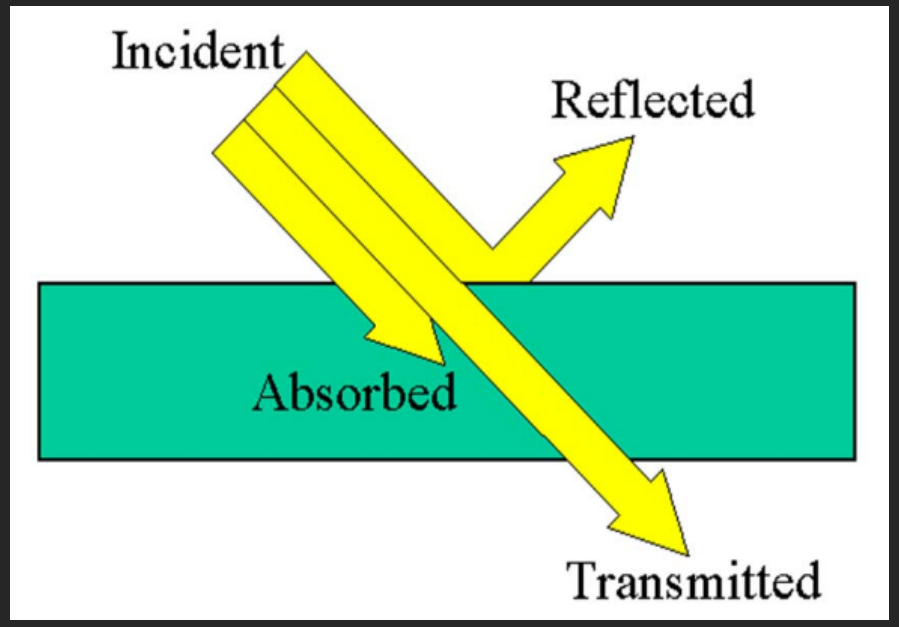

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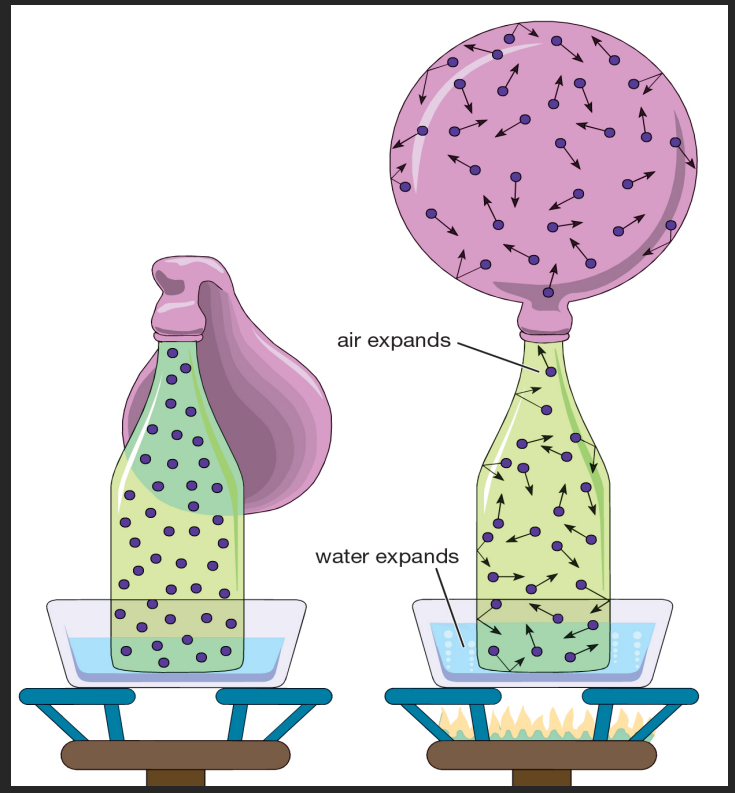

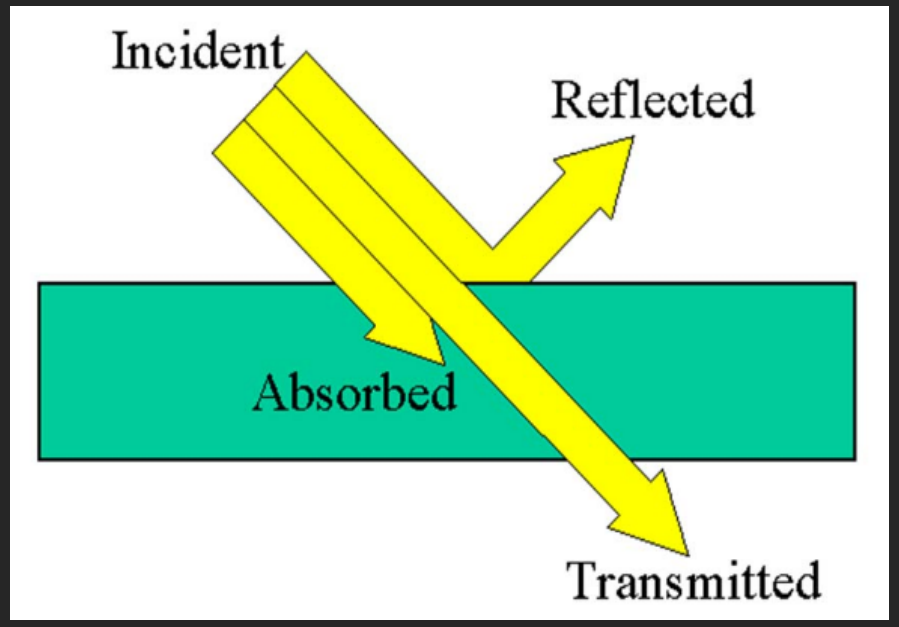

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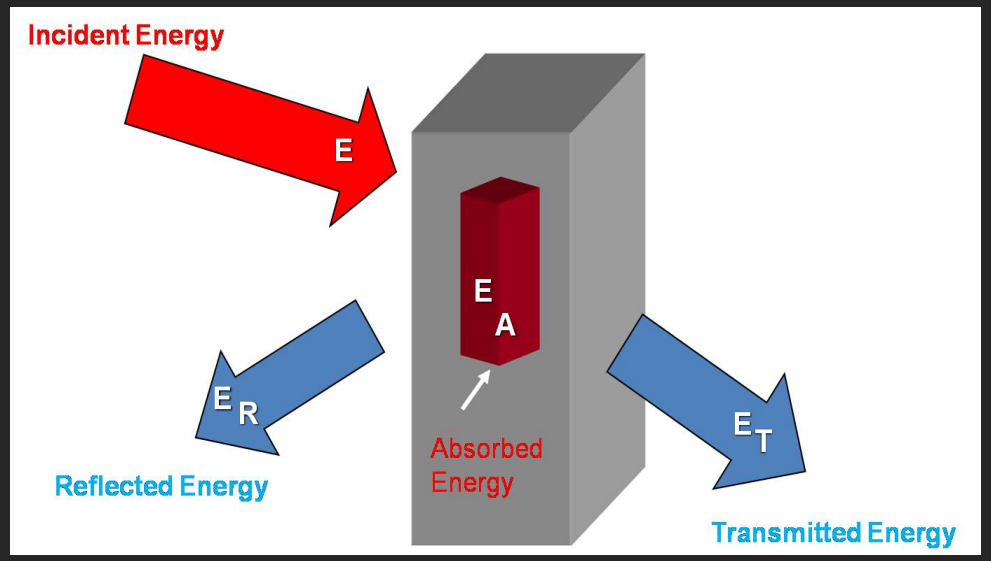

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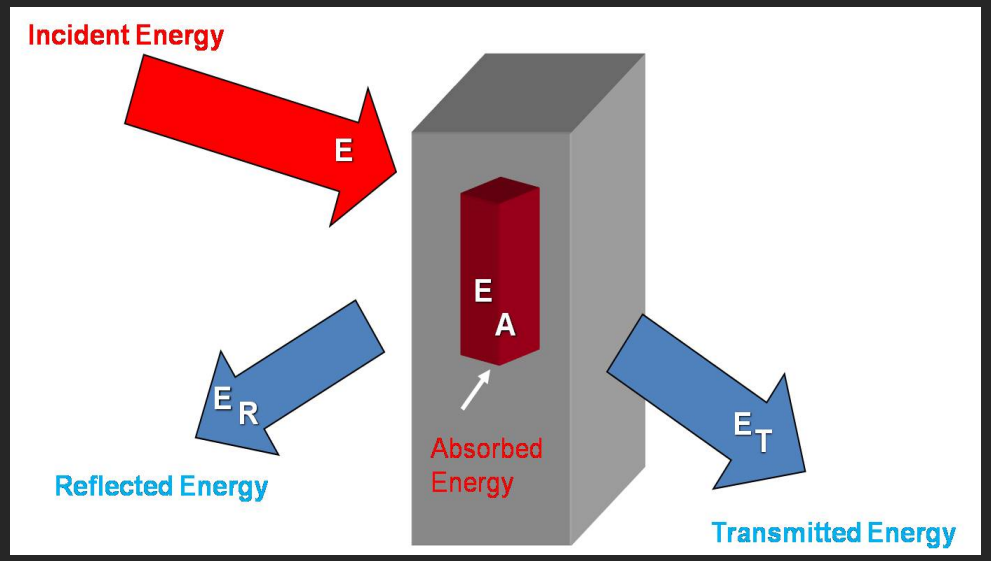

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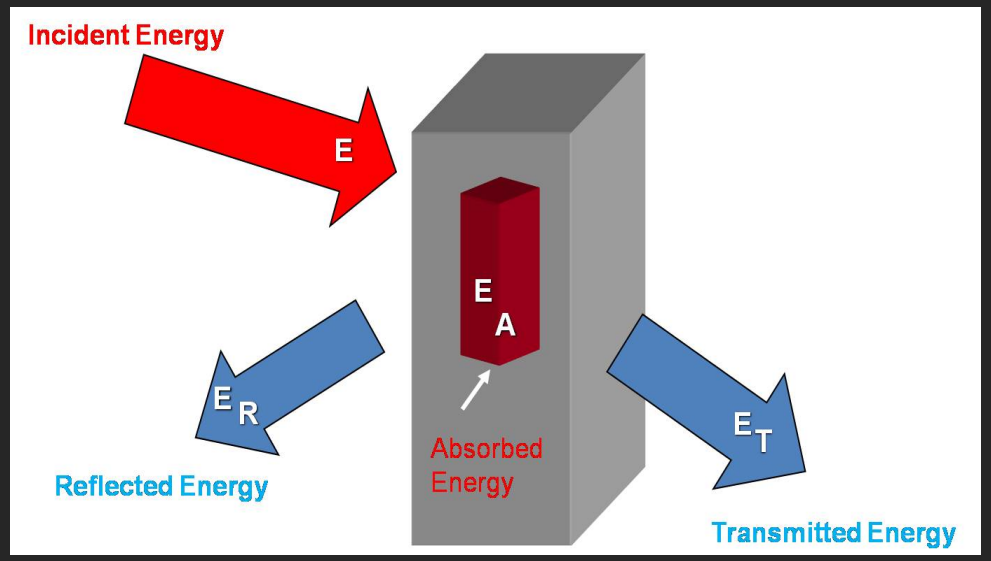

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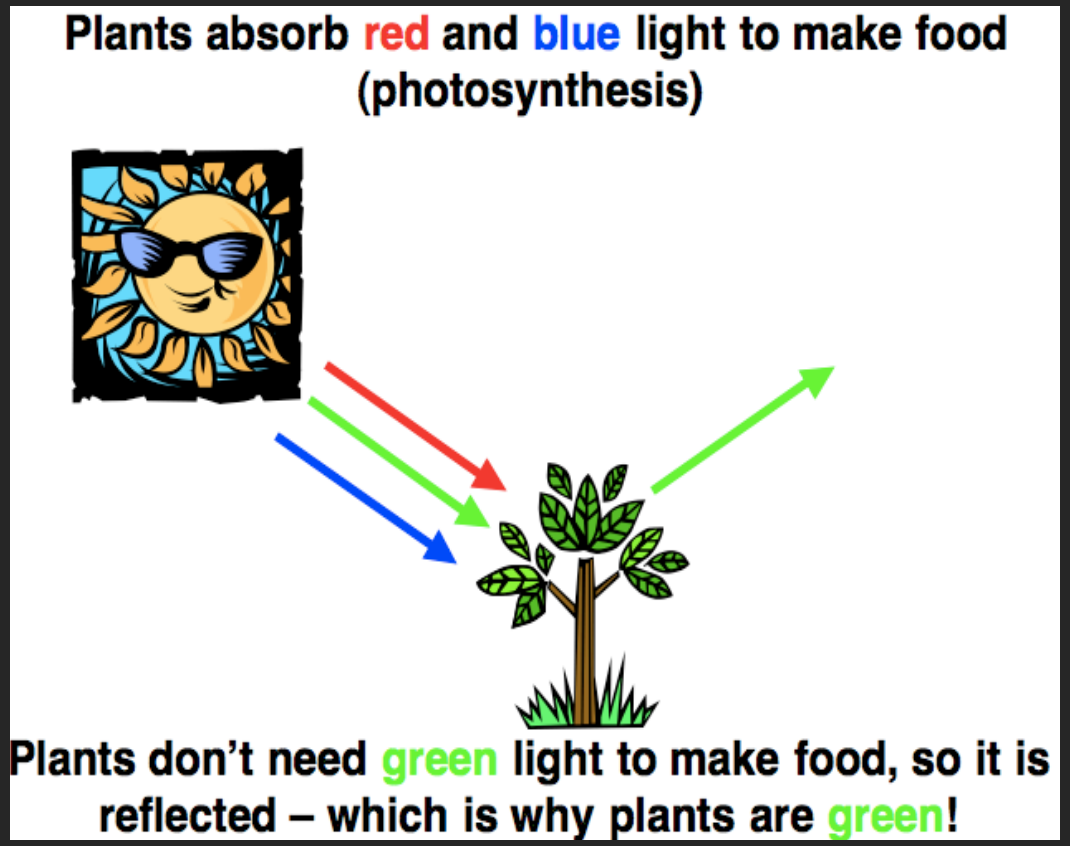

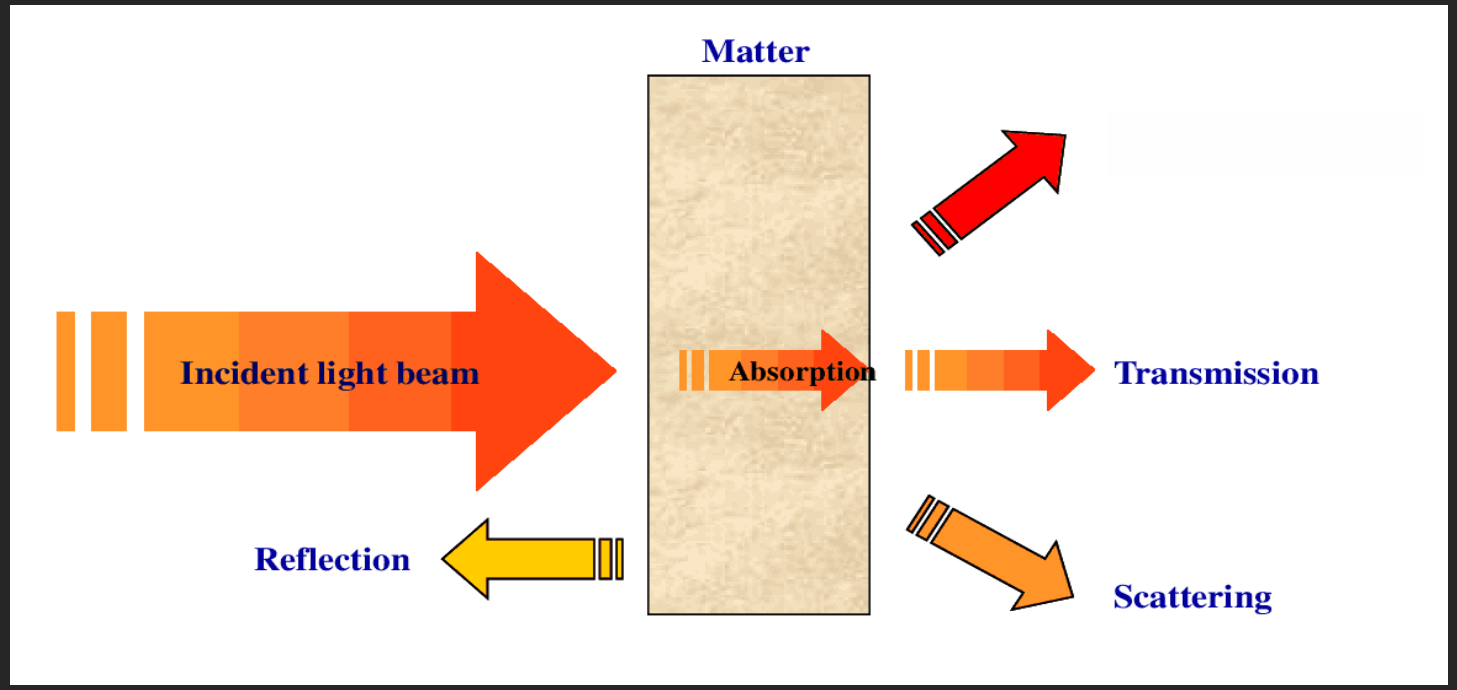

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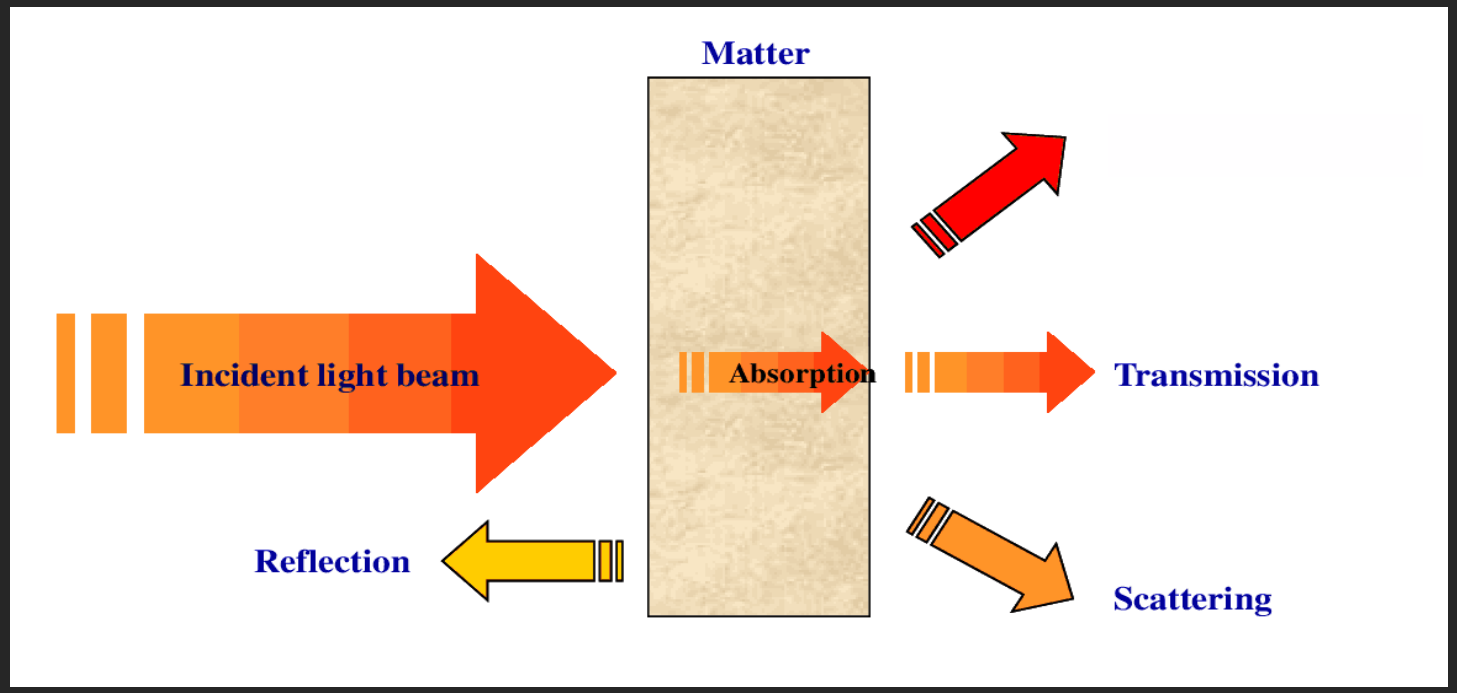

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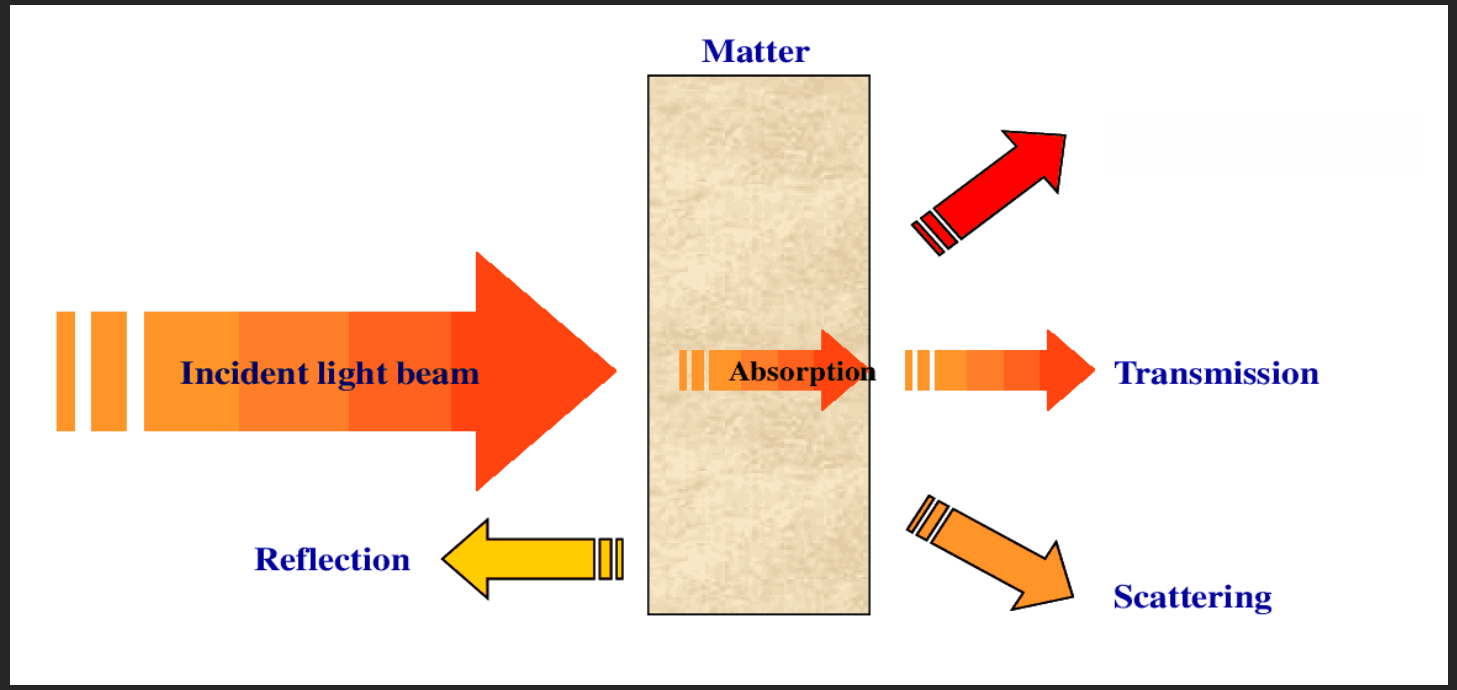
~ ***Radiation*** may ***bounce off*** an object and ***return*** to where it came from (***reflection***) or be ***redirected*** at many different angles (***scattering***).



~ The ***determining factors*** in whether radiation will be ***absorbed***, ***transmitted***, ***reflected***, or ***scattered*** are the ***wavelength*** of the radiation, and the ***size*** and ***properties*** of the ***object*** the radiation is striking.

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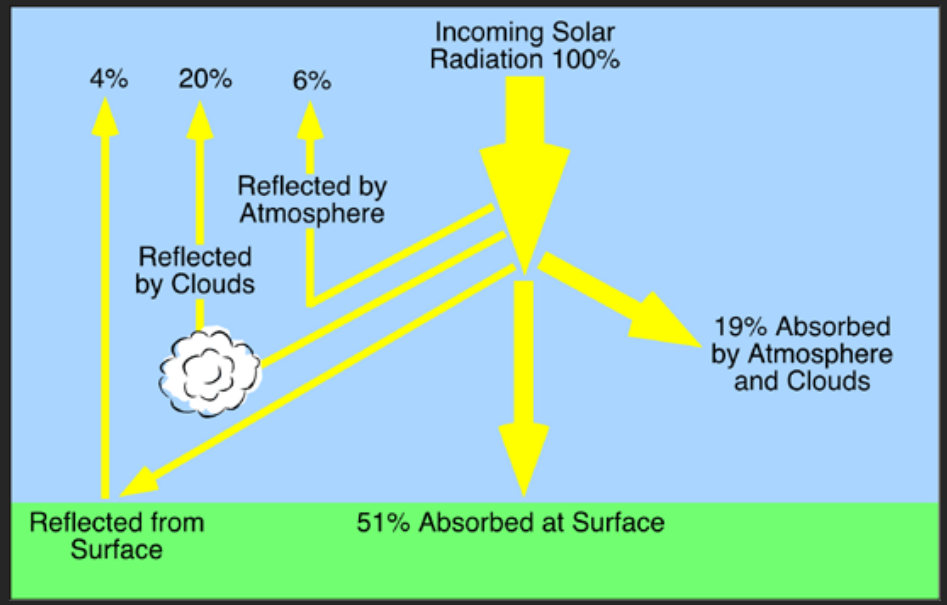

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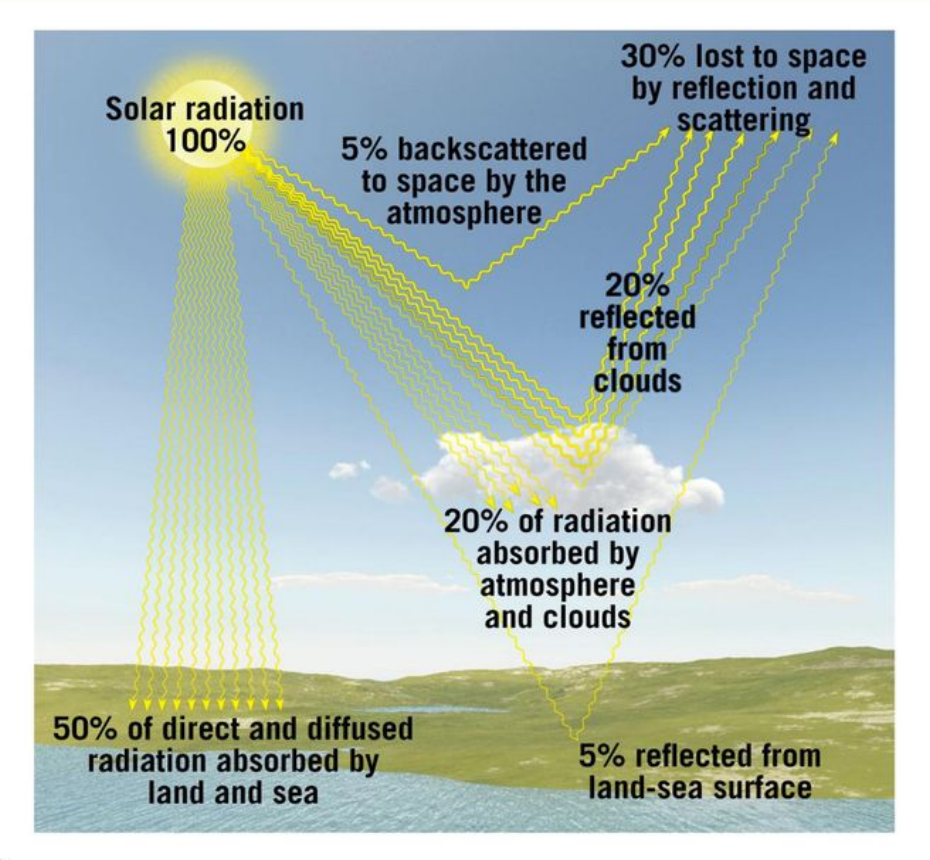

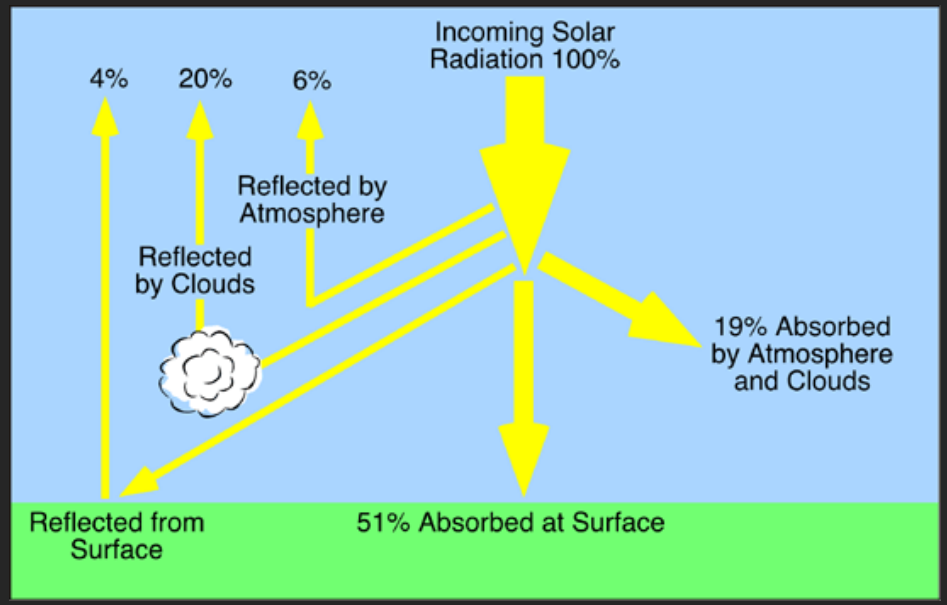

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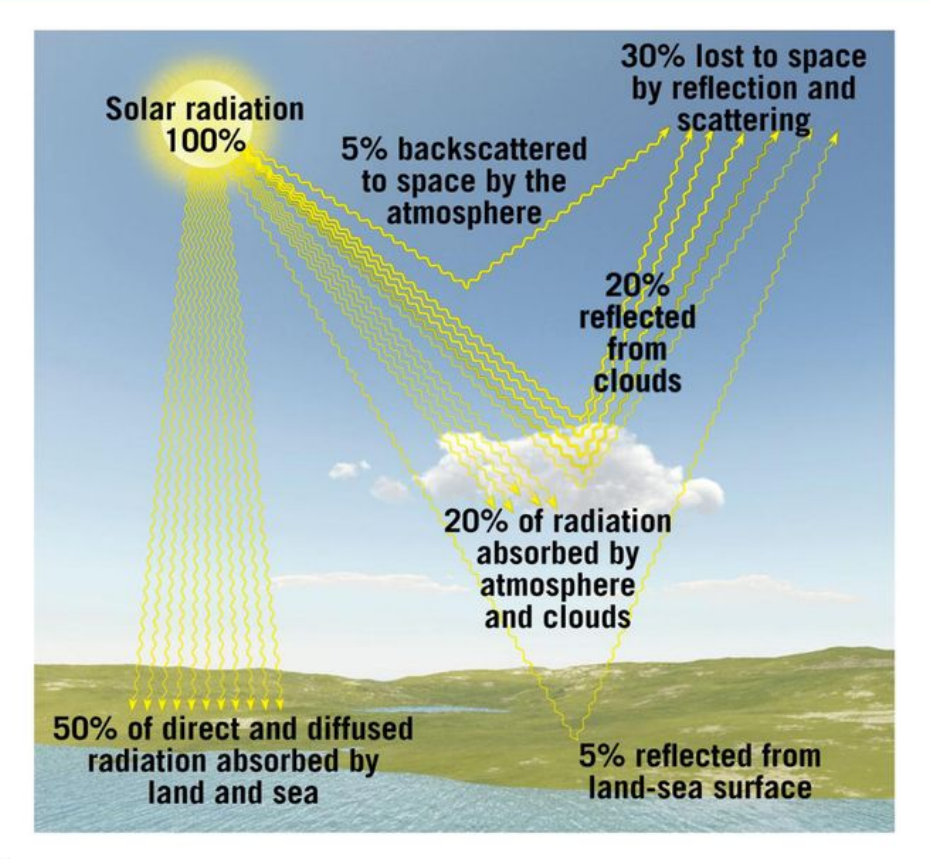
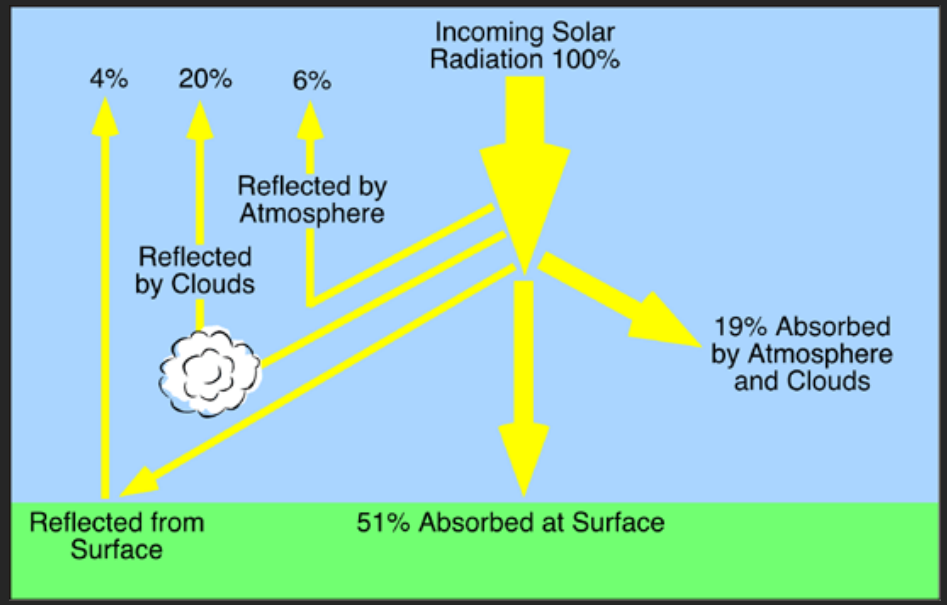
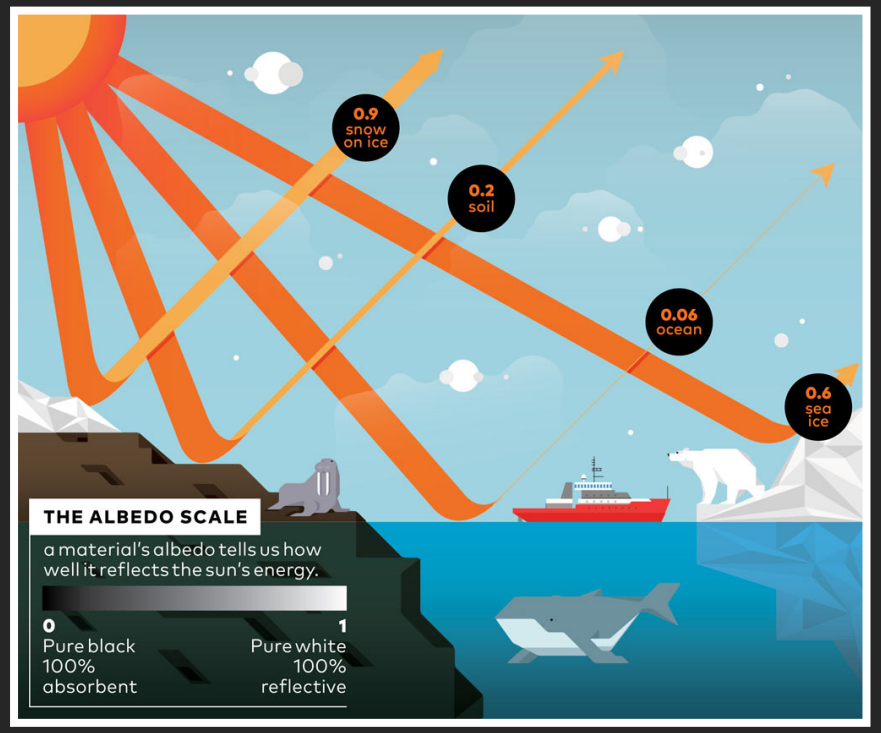




~ ***30%*** is ***reflected*** or ***scattered back*** into space by the gases, aerosols, clouds, and surface, while ***20%*** is ***absorbed*** by atmospheric gases and clouds.

~ The ***fraction*** of radiation ***reflected*** off an object is called its ***albedo***.



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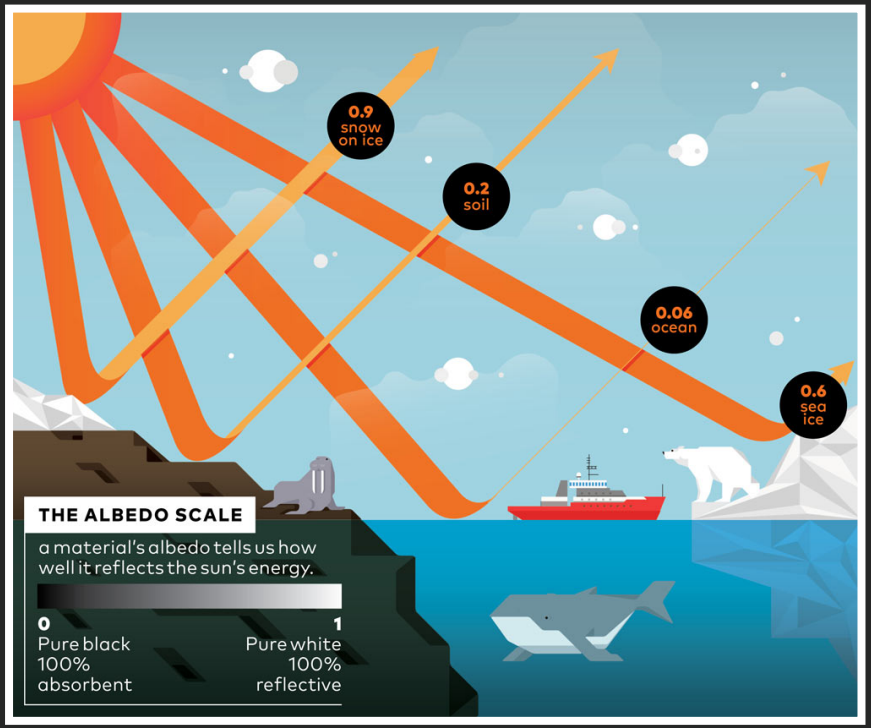

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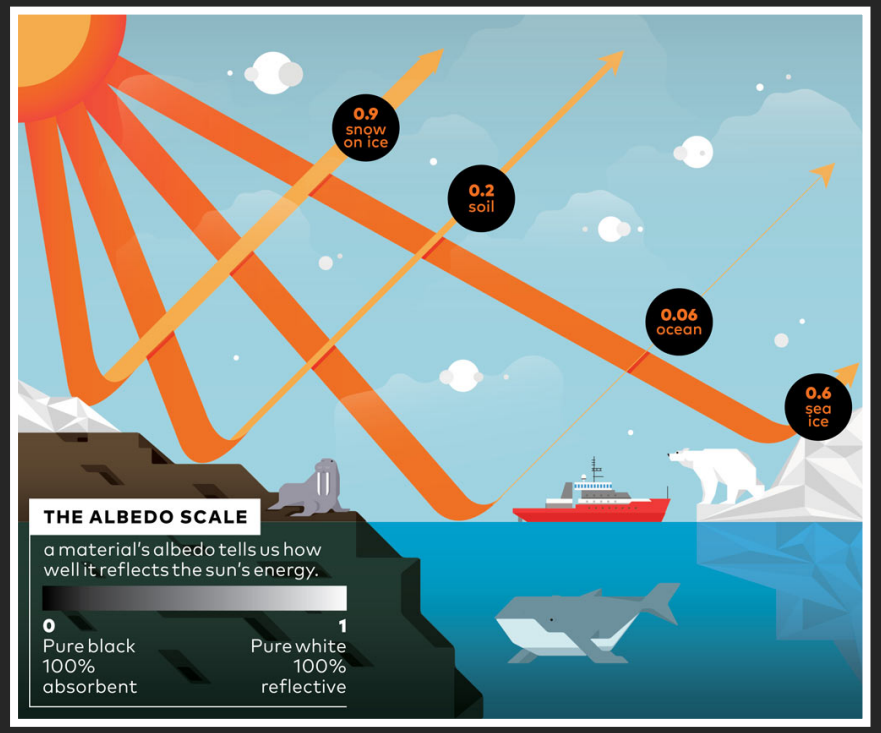

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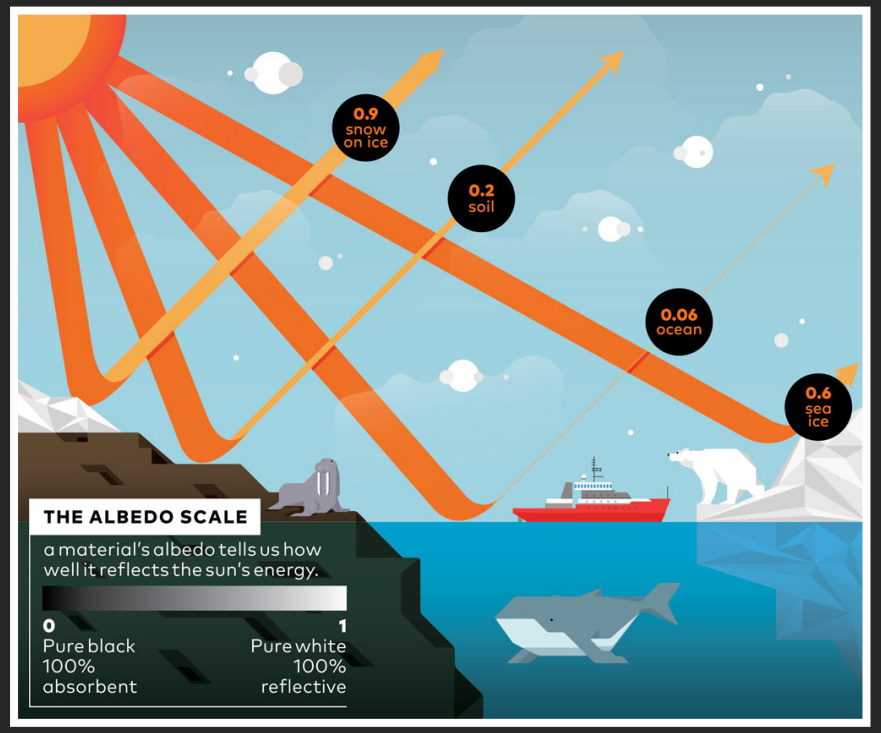

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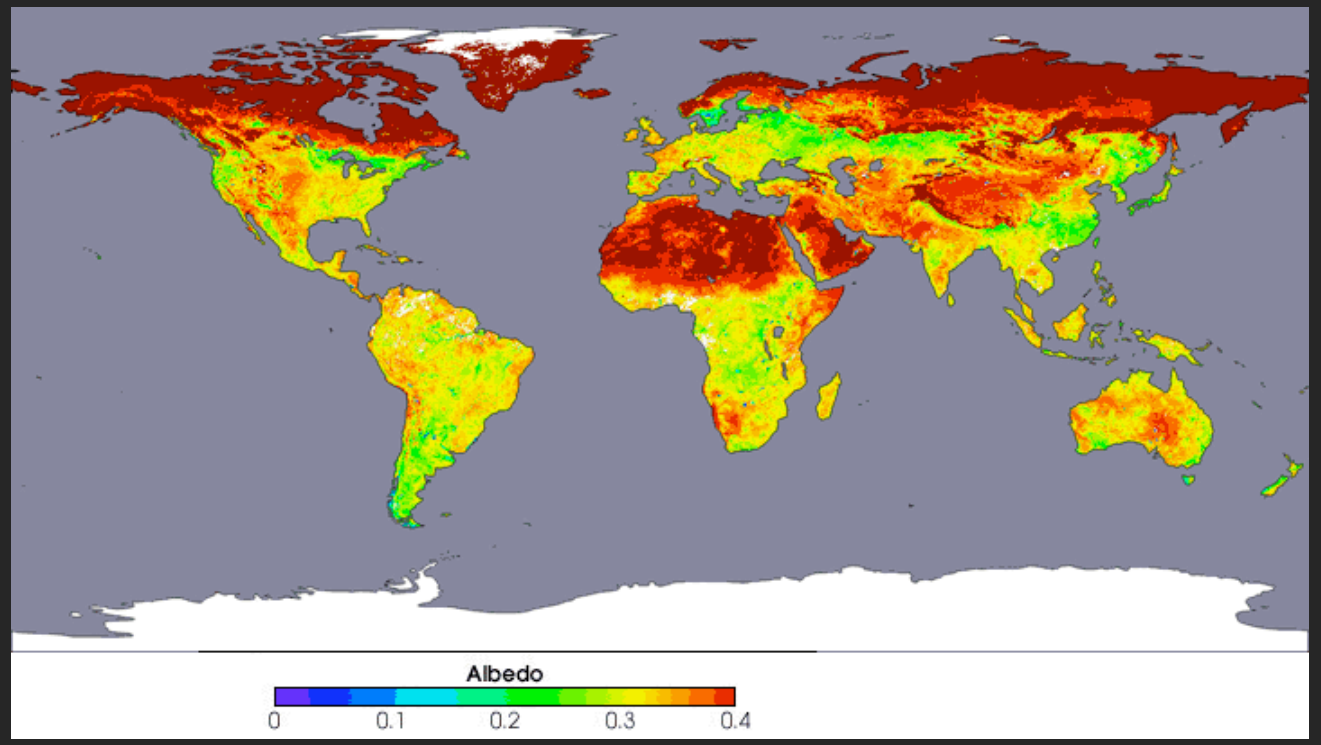
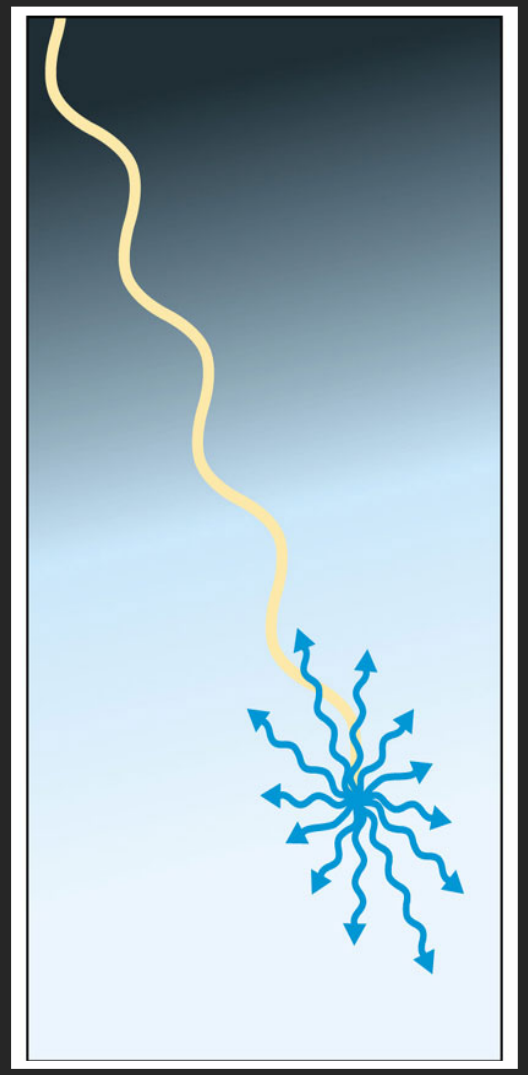


~ ***Scattering diffuses*** radiation, sending it in many ***different directions*** at ***weaker*** intensity.



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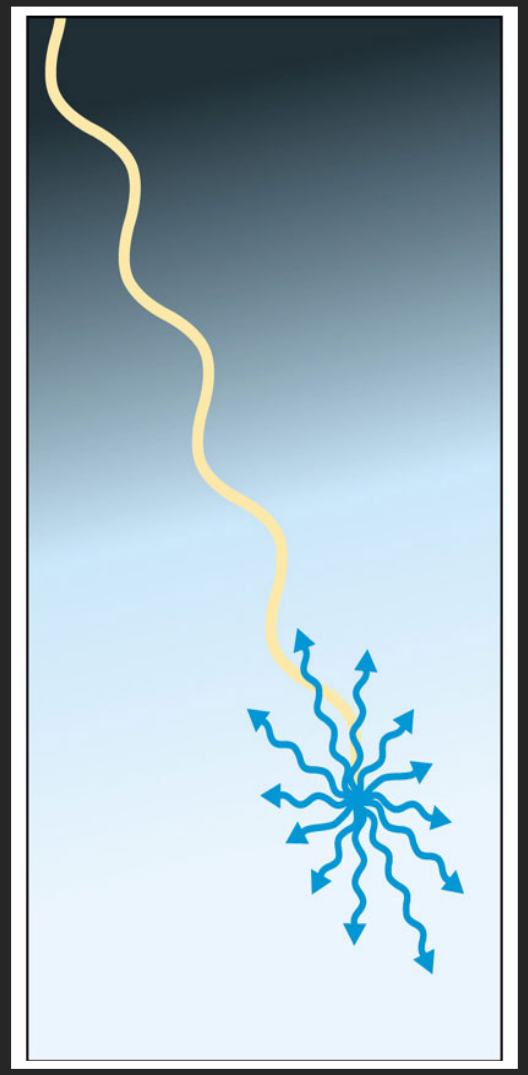

~ In the atmosphere, ***aerosols*** and ***gases*** ***scatter*** light from the Sun explaining why ***shadows*** are ***never pitch black***.

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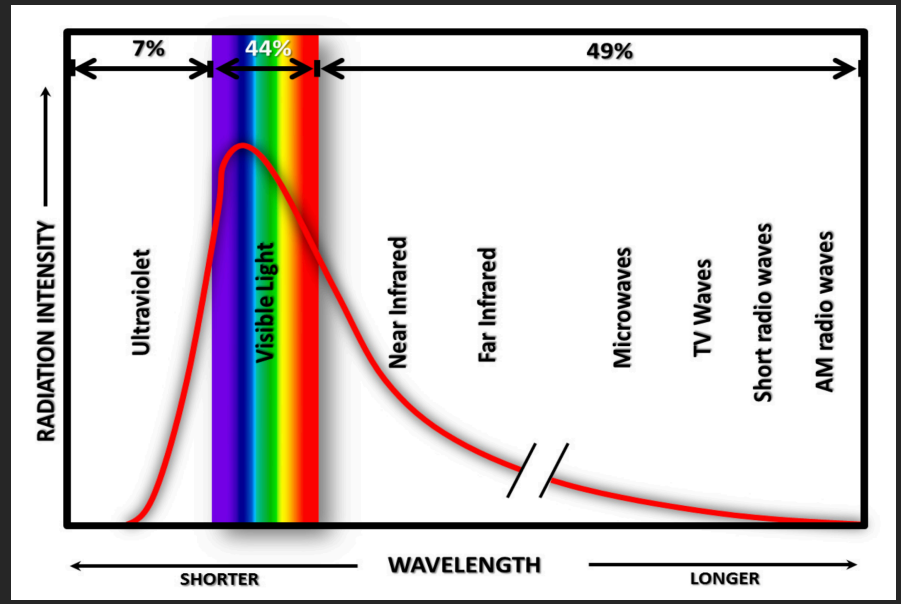

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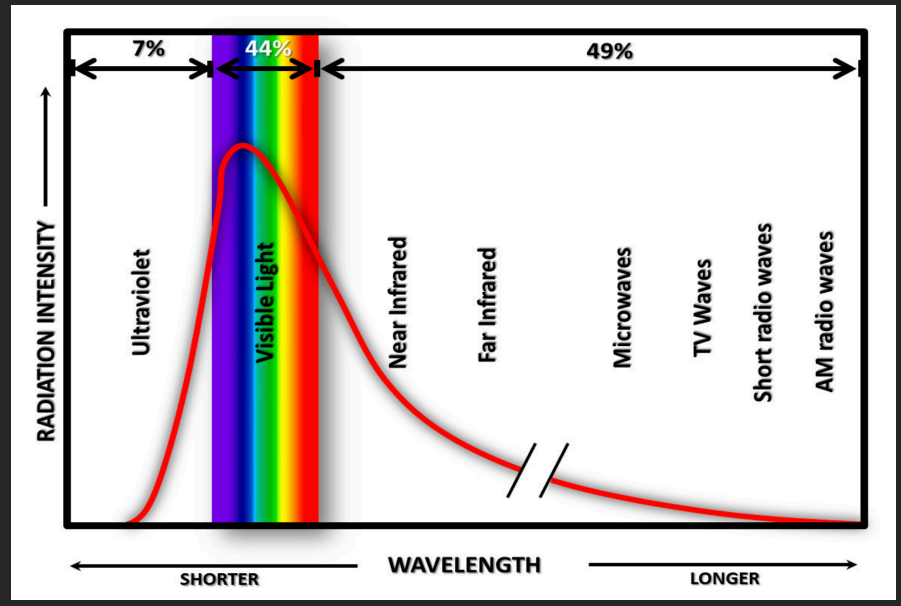

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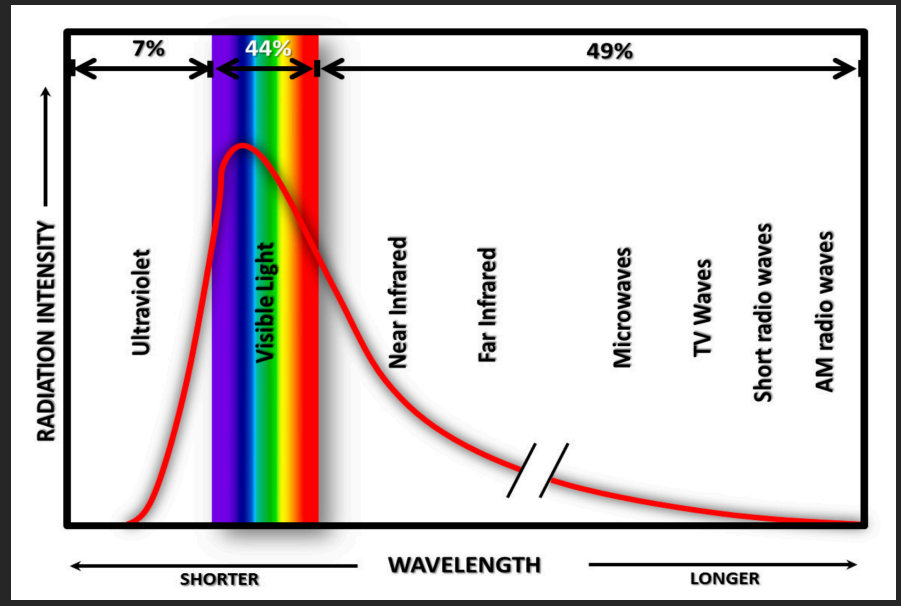

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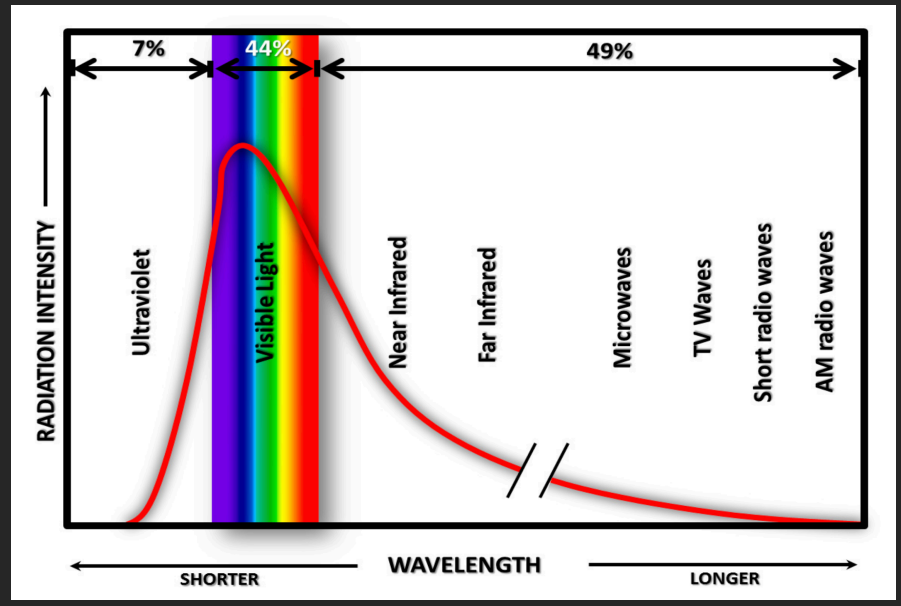

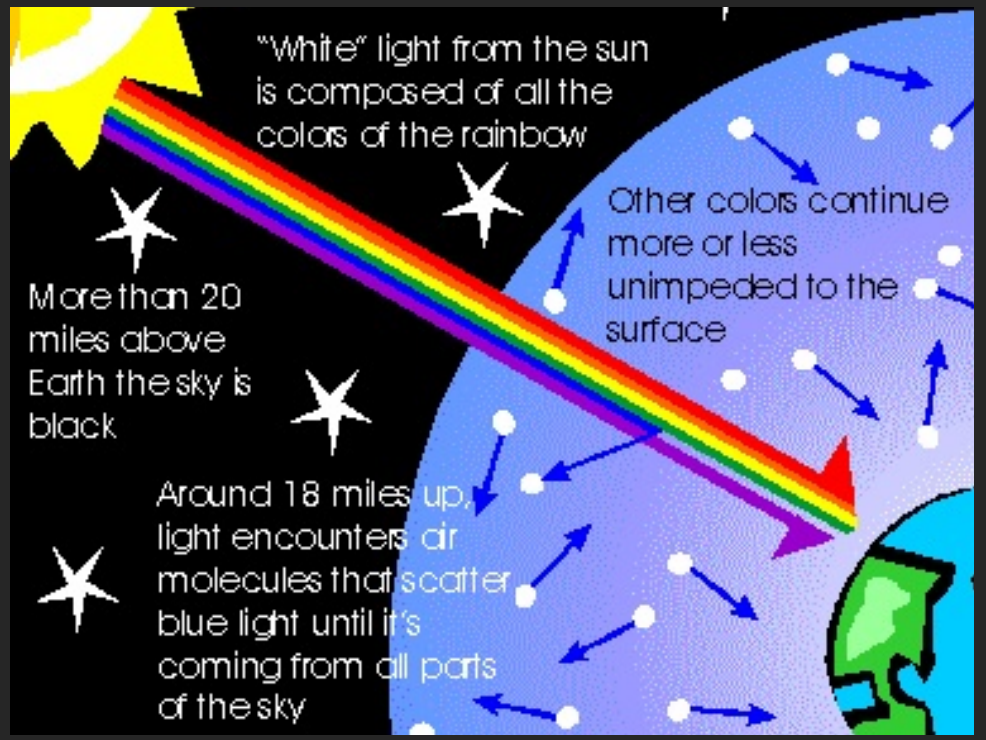

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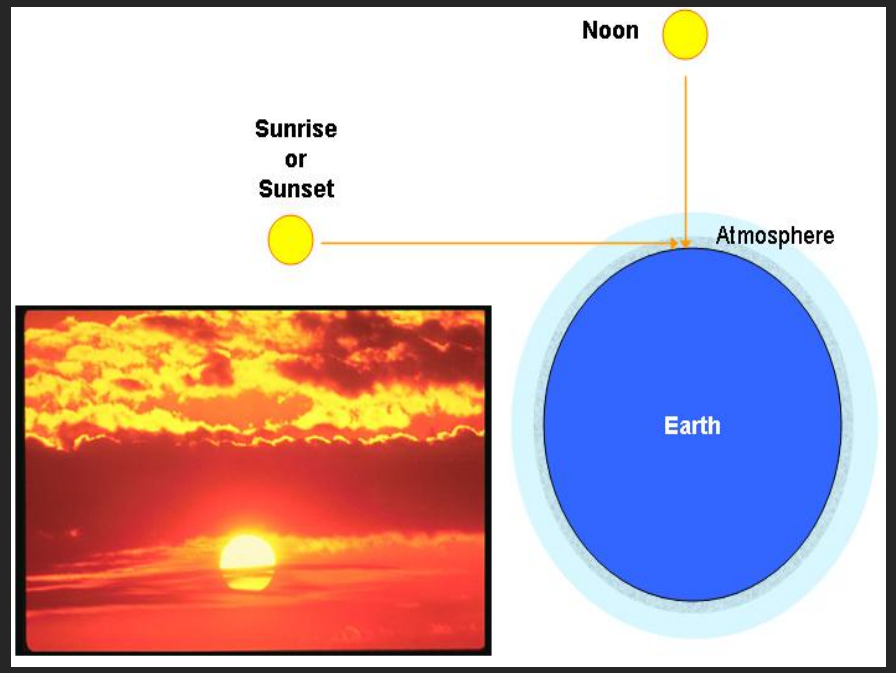

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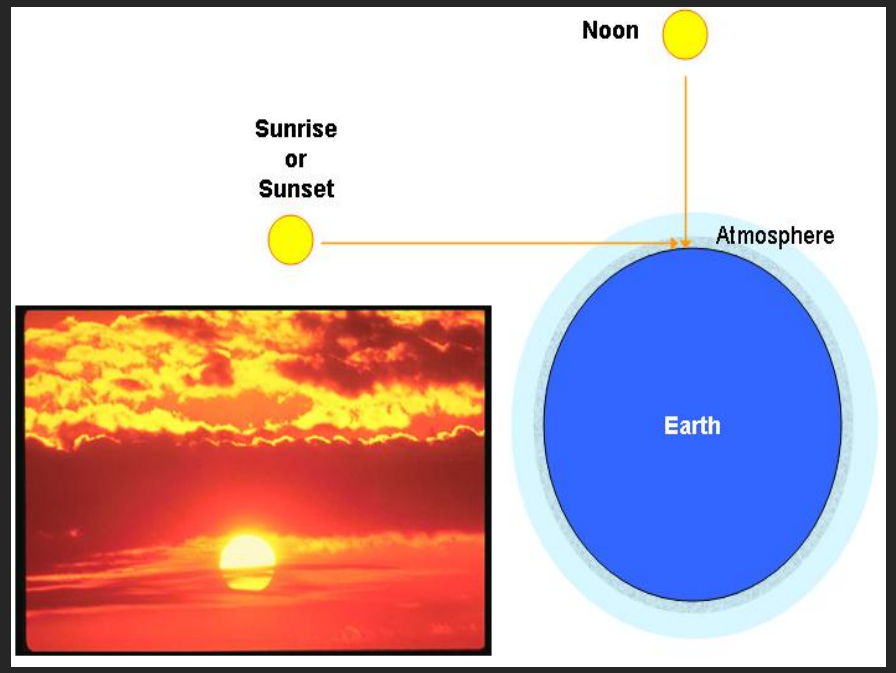

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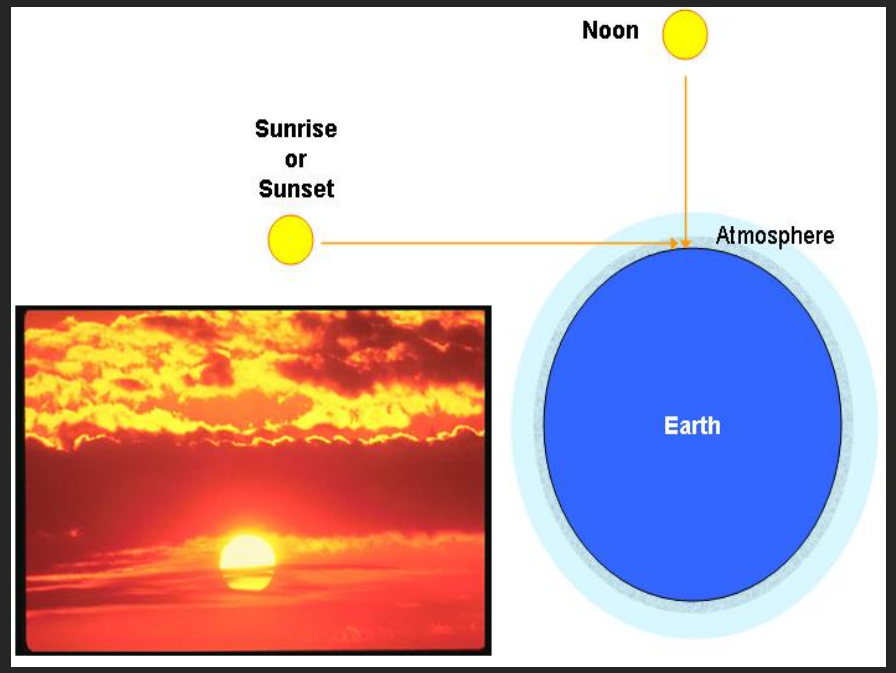

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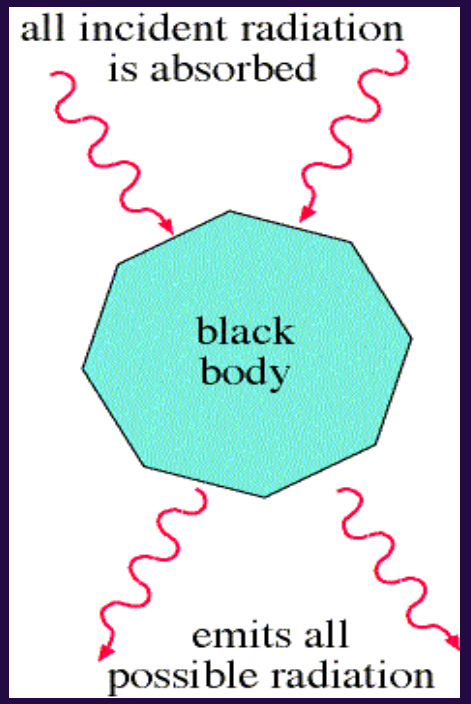

4) Objects that are ***good emitters*** of radiation are also ***good absorbers*** of radiation.

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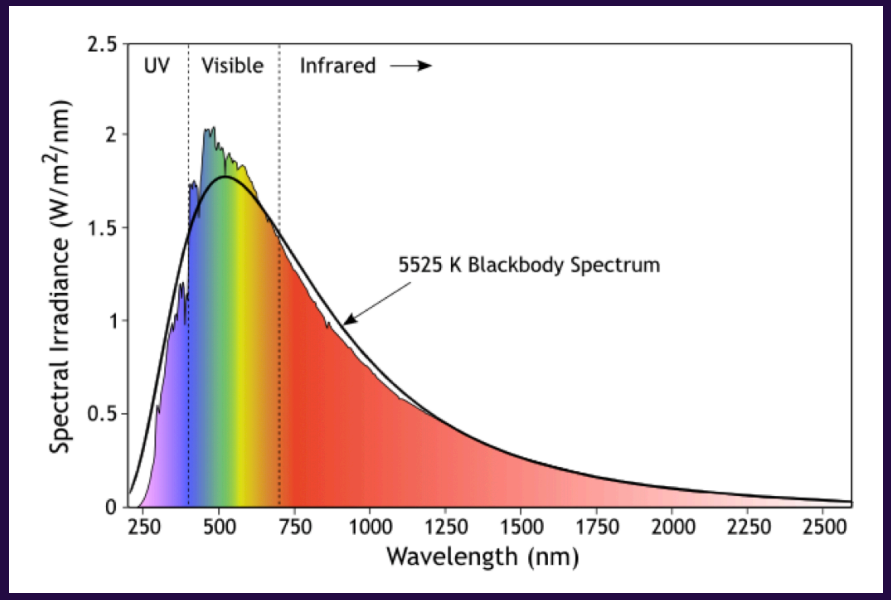

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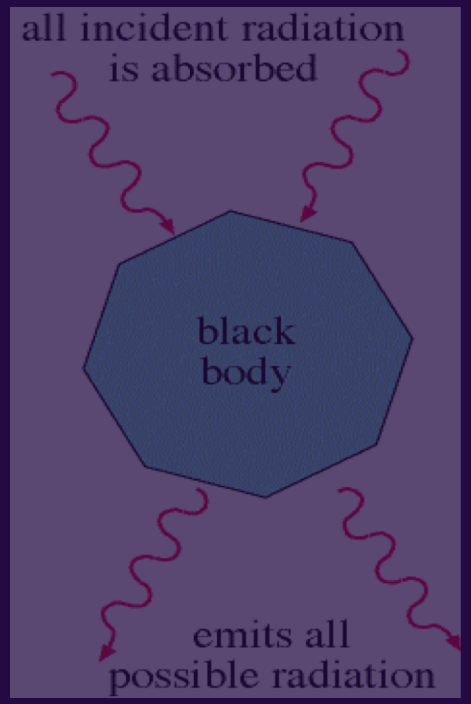

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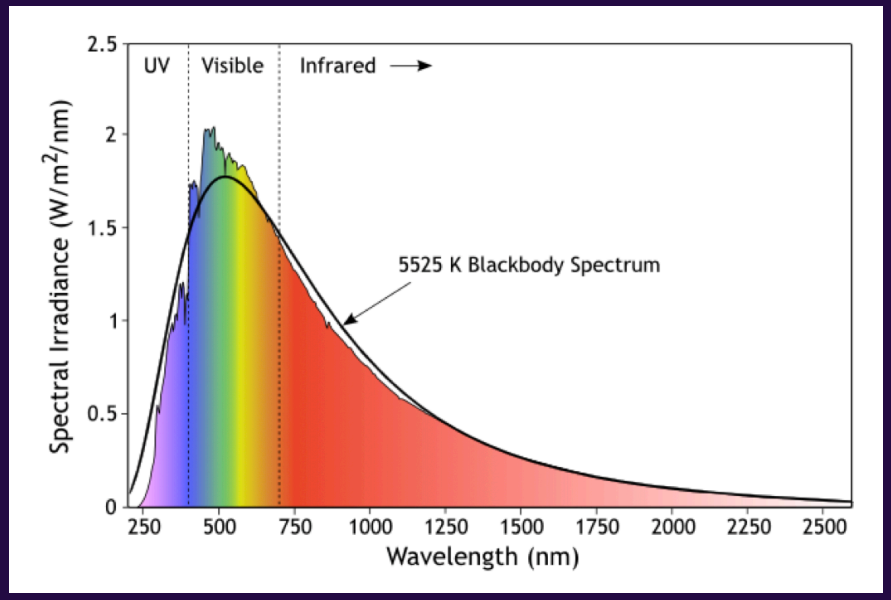

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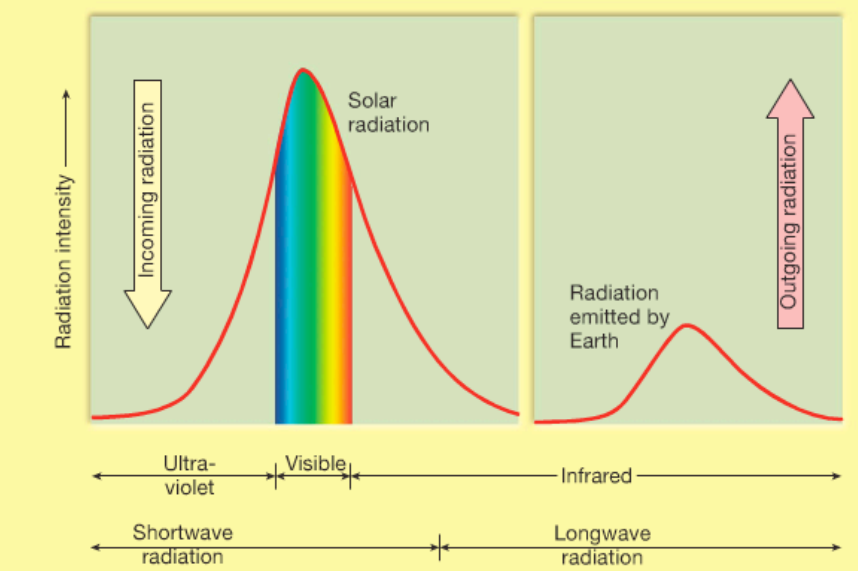

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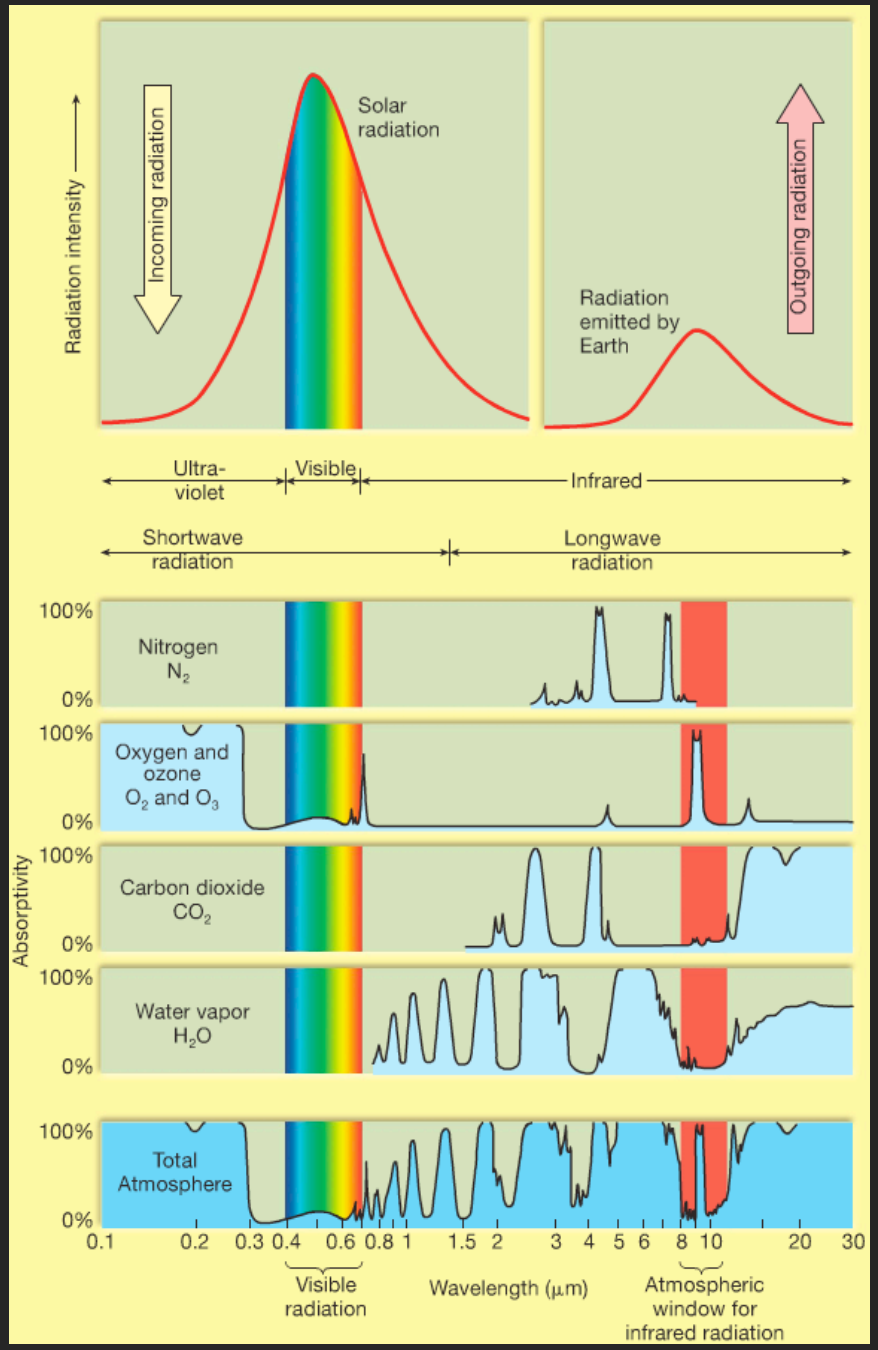

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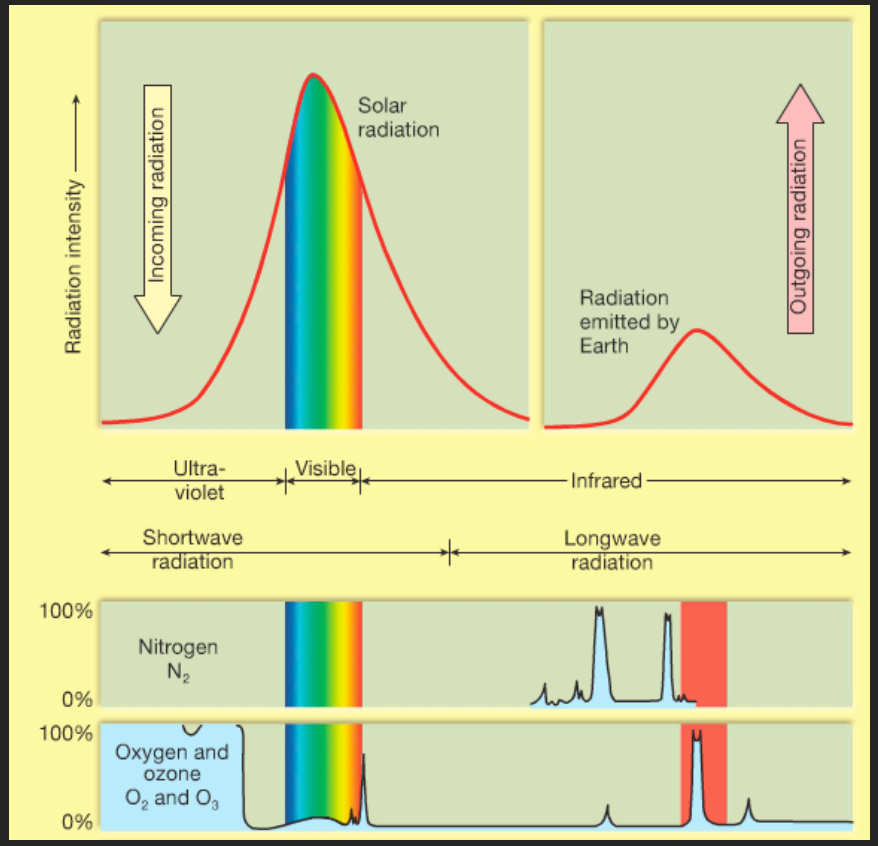

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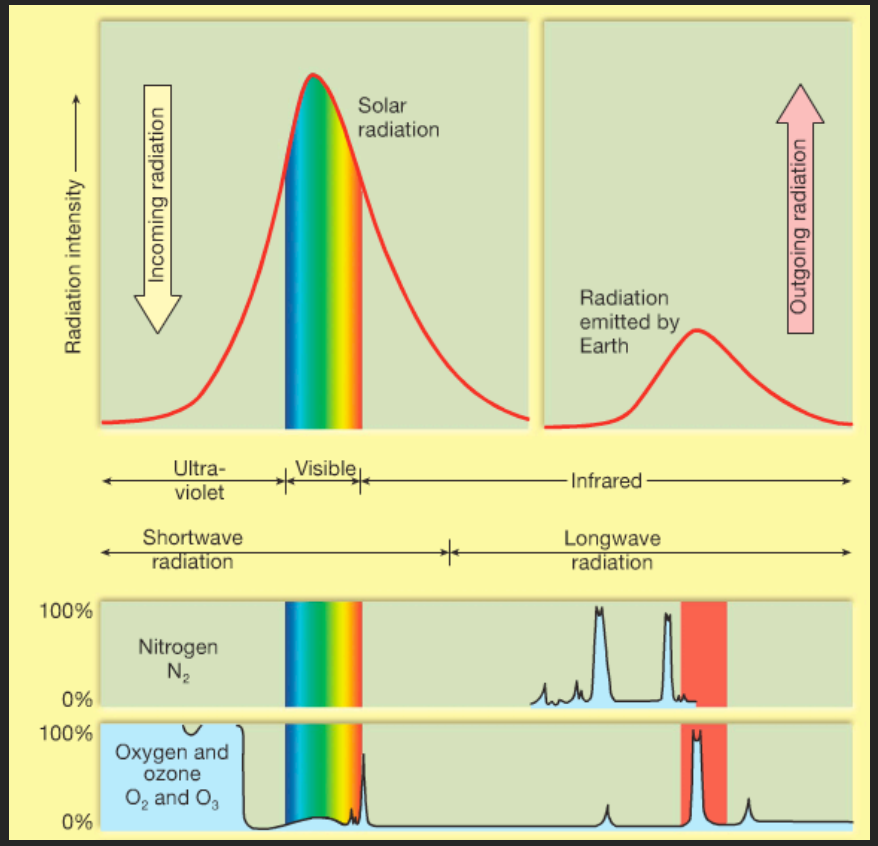
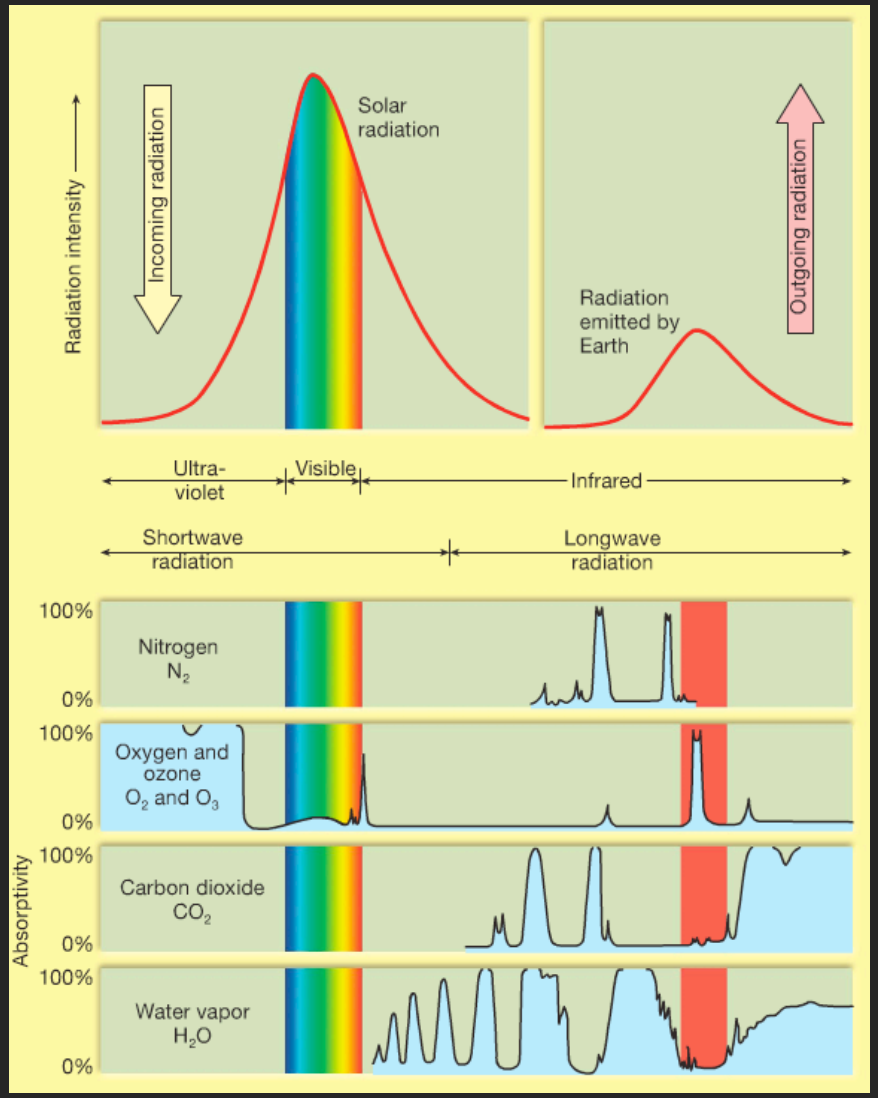
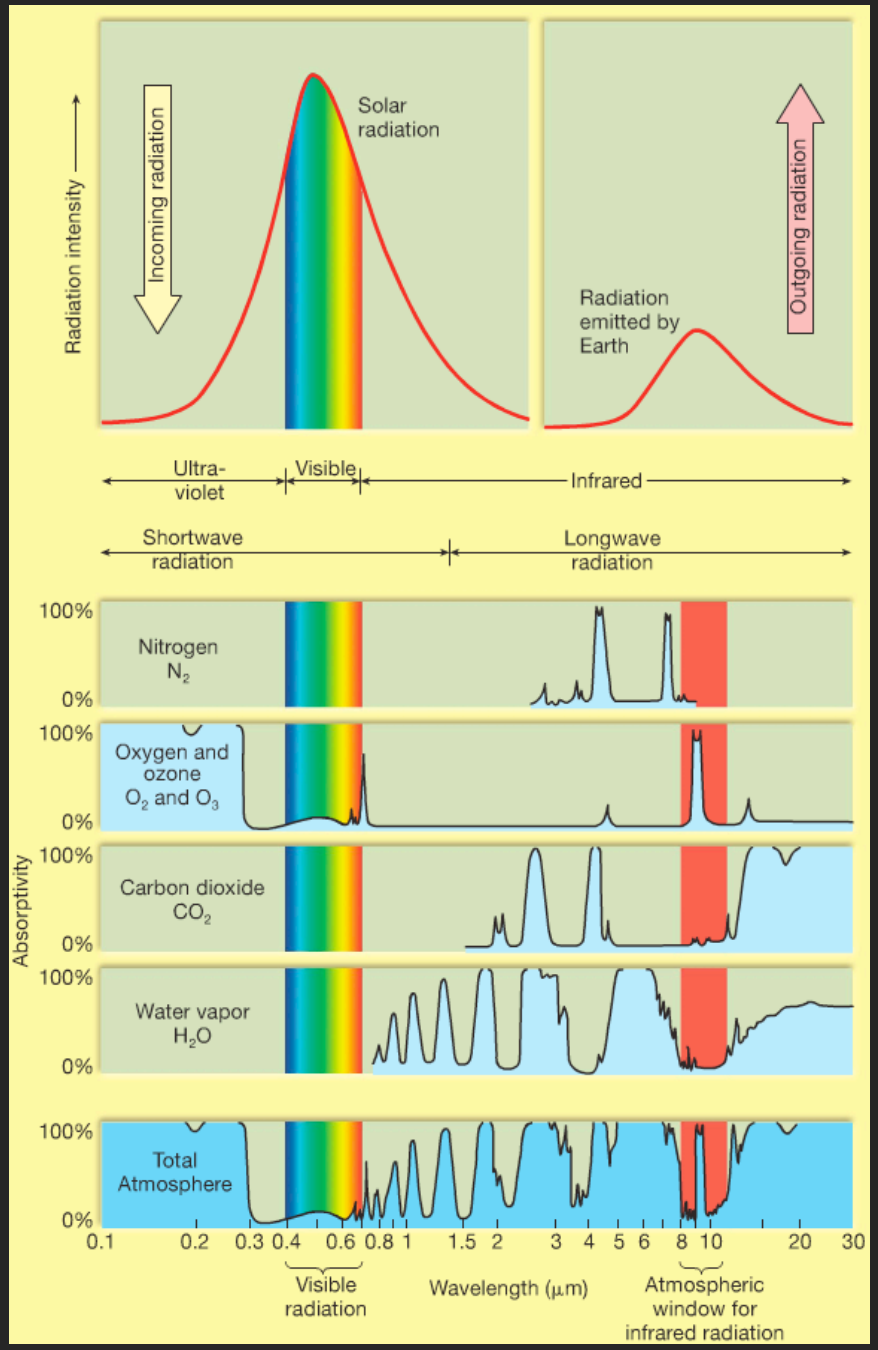
~ O_2 and O_3 have very ***high absorptivity*** in the ***UV*** band of the spectrum, making life possible on Earth.



~ O_2 and O_3 are the ***only gases*** with any ***absorptivity*** in the ***visible*** band, ***allowing*** this largest fraction of the Sun's radiation be mostly ***transmitted*** through the atmosphere.



~ In the ***infrared*** portion of the ***Sun's*** spectrum, ***water vapor*** (clouds) is a ***strong absorber*** with a small amount of absorptivity from ***carbon dioxide***.



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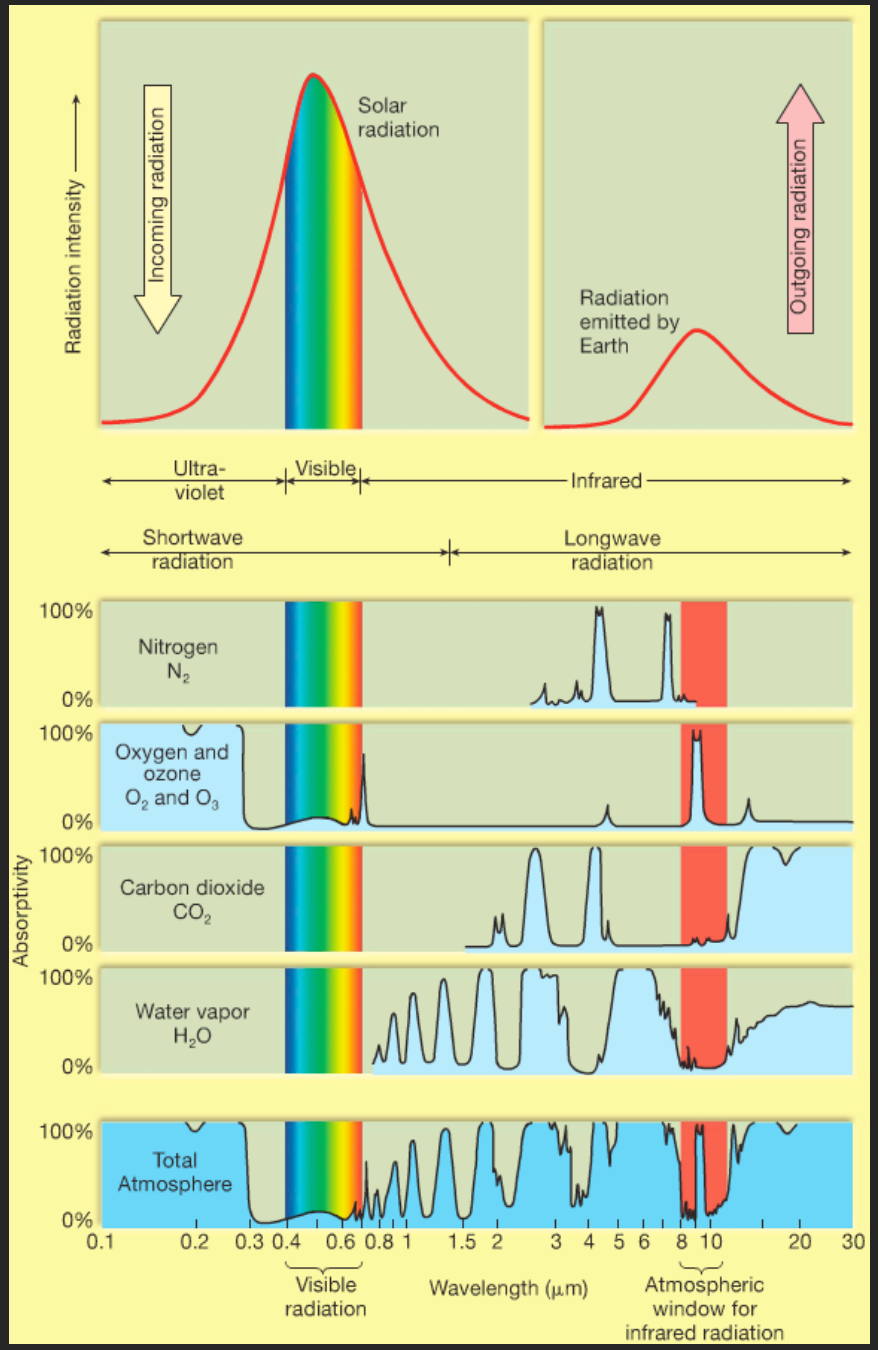
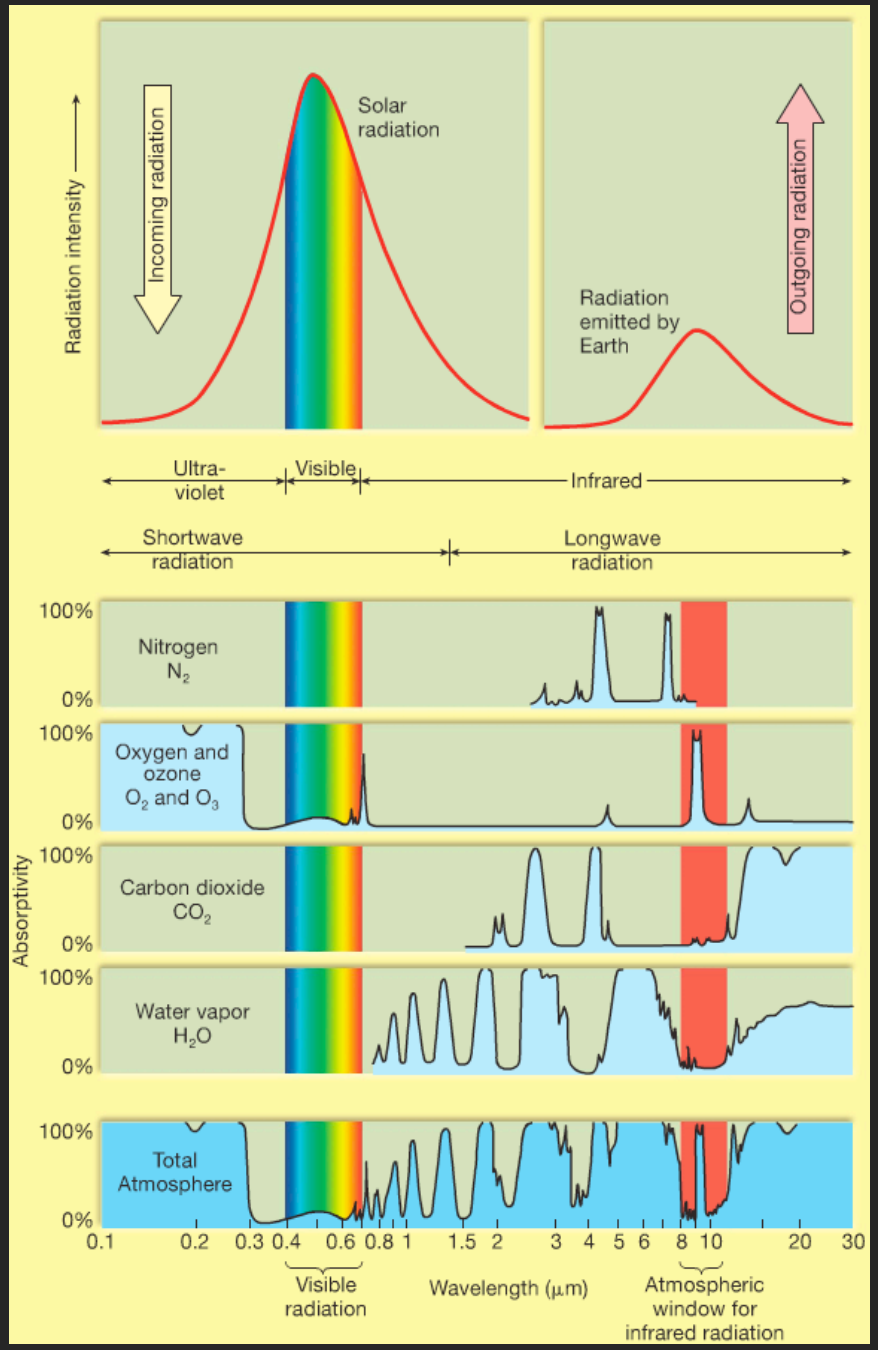
~ Thus, ***most incoming solar*** radiation is ***transmitted*** through the atmosphere ***to*** the ***ground*** and ***solar radiation*** is ***not*** an ***effective heater*** of the ***atmosphere***.



~ Looking at the ***Earth's radiation*** spectrum, atmospheric ***gases*** are ***much better*** at ***absorbing*** this ***longer wavelength*** radiation.



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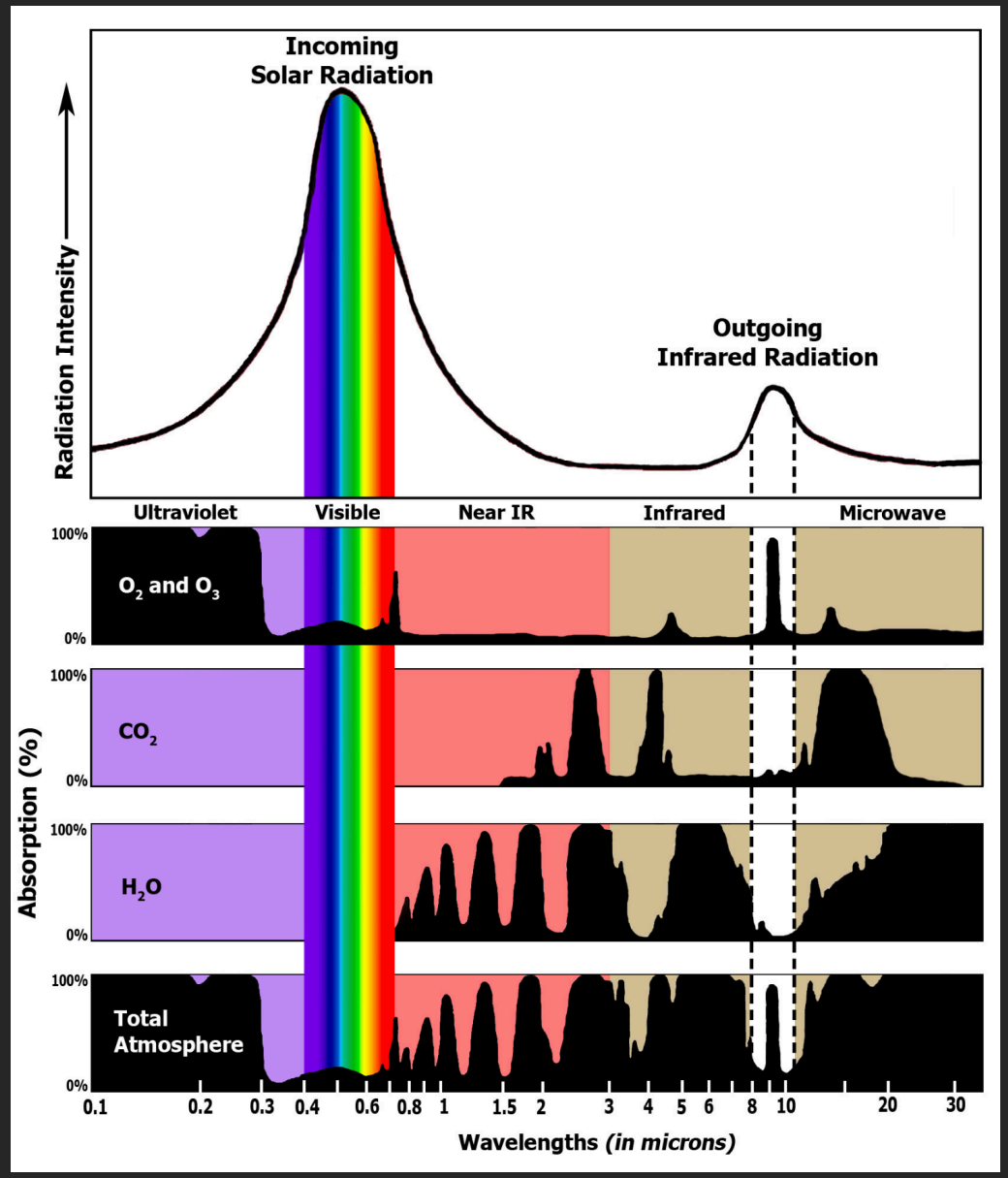
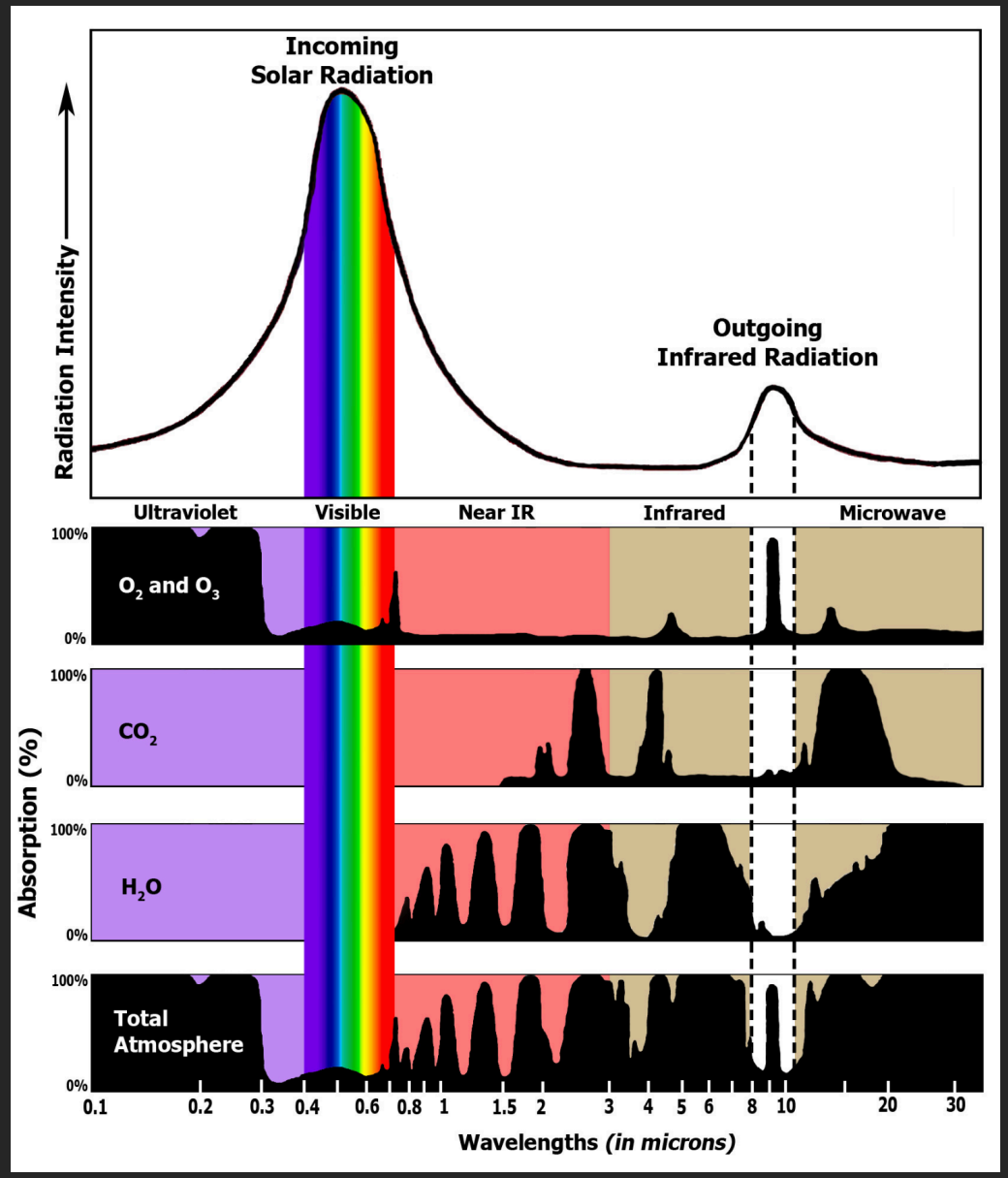
~ ***Carbon dioxide***, and ***water vapor***, are the ***best absorbers*** in this area of the spectrum, but oxygen, ozone, and nitrogen also contribute.


Incoming
Solar Radiation
Outgoing
Infrared Radiation
Radiation Intensity
Ultraviolet
Visible
Near IR
Infrared
Microwave
100%
0%
O_2 and O_3
CO_2
H_2O
Total
Atmosphere
Absorption (%)
0.1
0.2
0.3
0.4
0.6
0.8
1
1.5
2
3
4
5
6
8
10
20
30
Wavelengths (in microns)

~ Since the ***atmosphere*** is mostly ***transparent*** to incoming ***solar*** radiation and much more ***absorbing*** of the ***Earth's***, longwave radiation, the ***atmosphere*** is ***heated*** from the ***ground up***.



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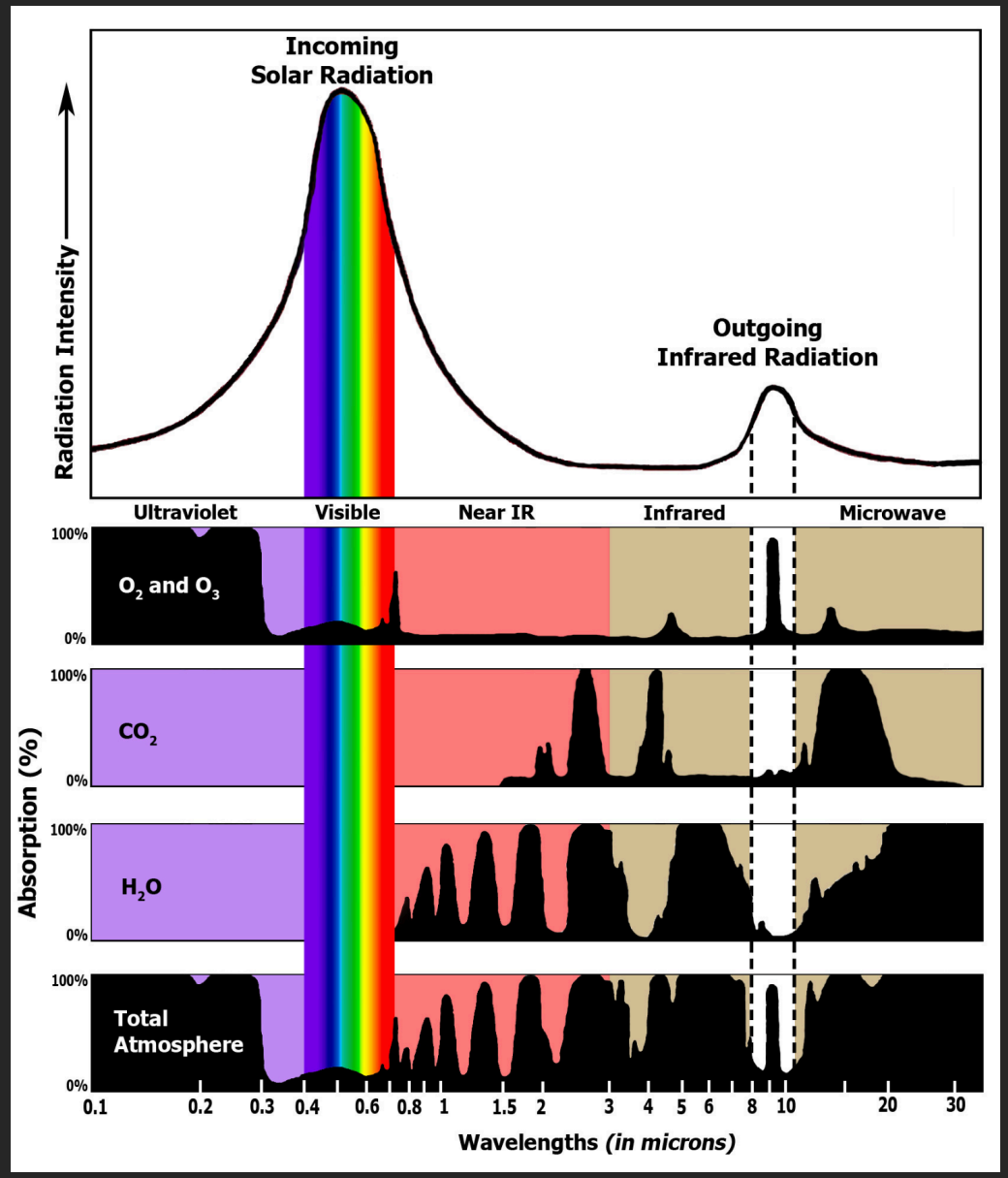
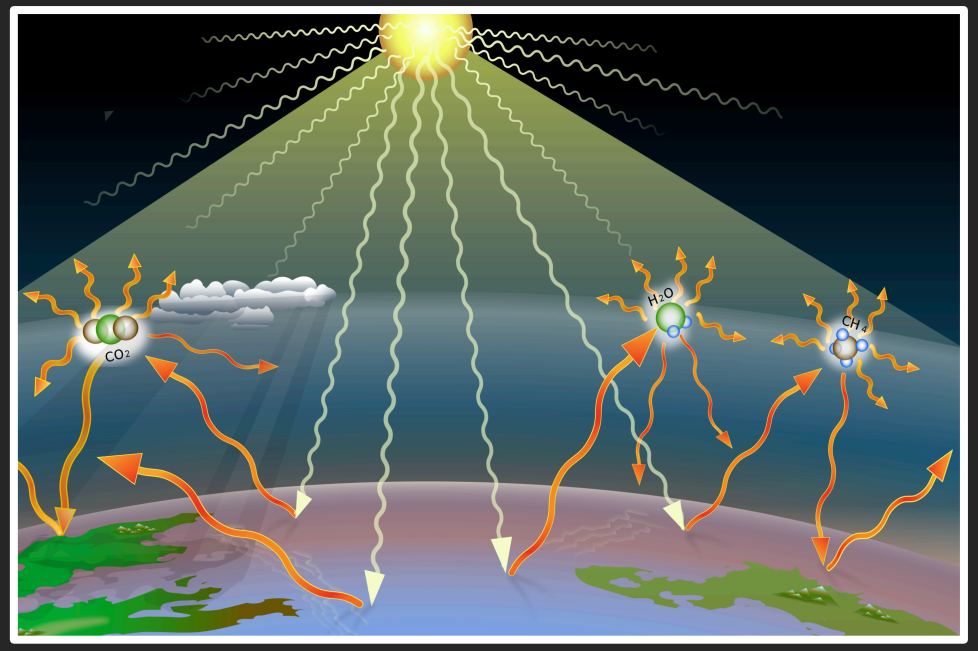
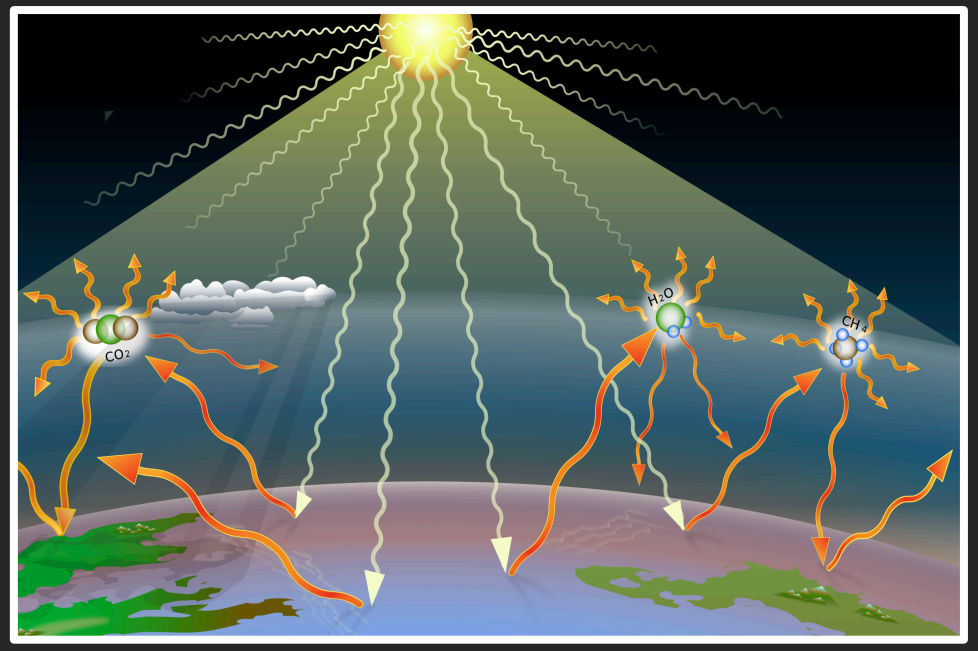
~ If the ***Earth*** had ***no atmosphere***, the ***planet*** would have an average ***temperature*** around ***freezing***.





~ The ***water vapor*** and ***carbon dioxide*** ***absorb*** the ***radiation*** emitted by the Earth, and then ***emit*** radiation that further ***heats*** the ***atmosphere***, warming the planet to ***~60˚ F*** (on average).



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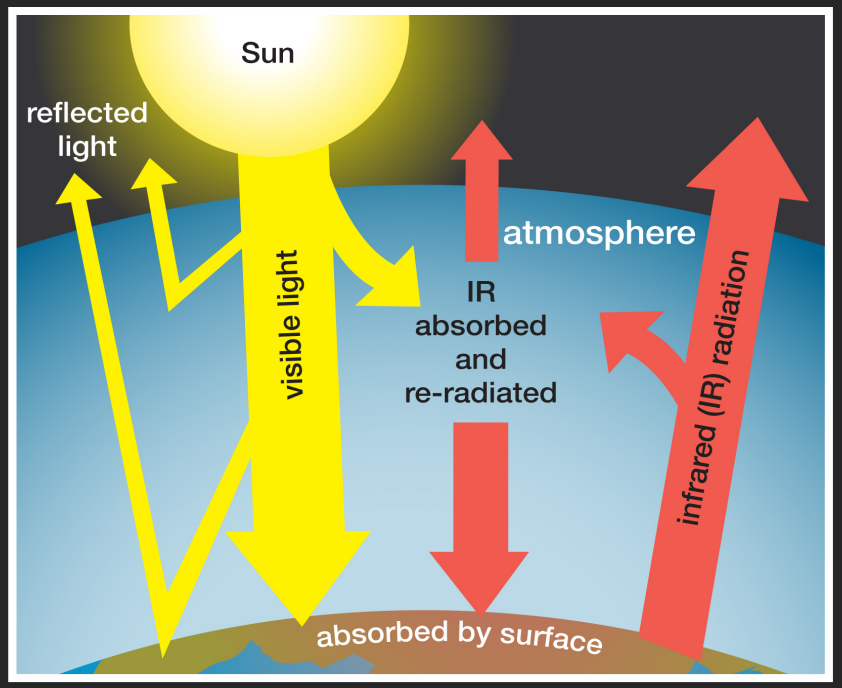

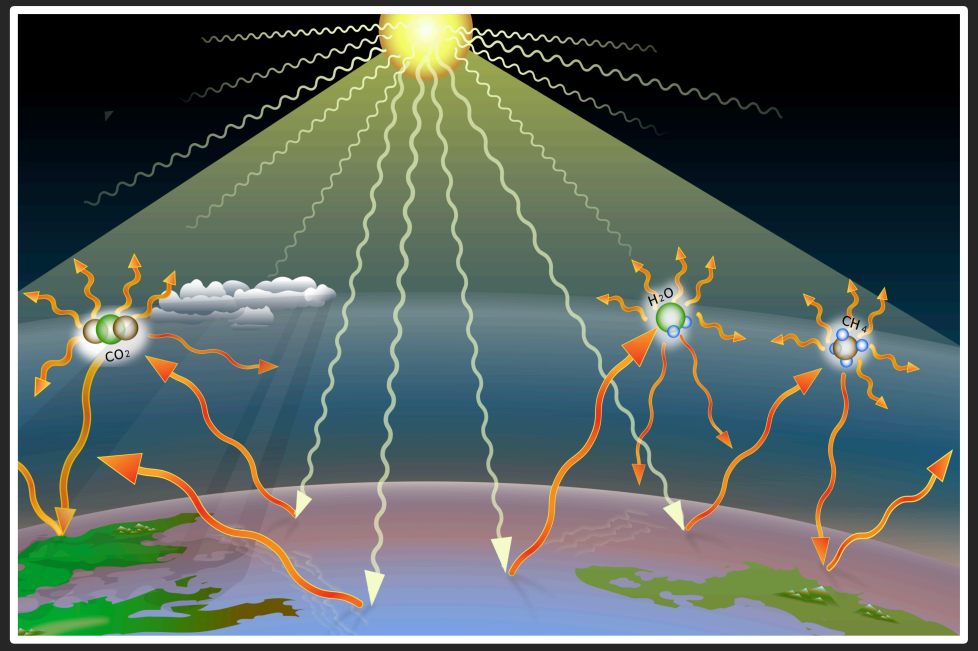

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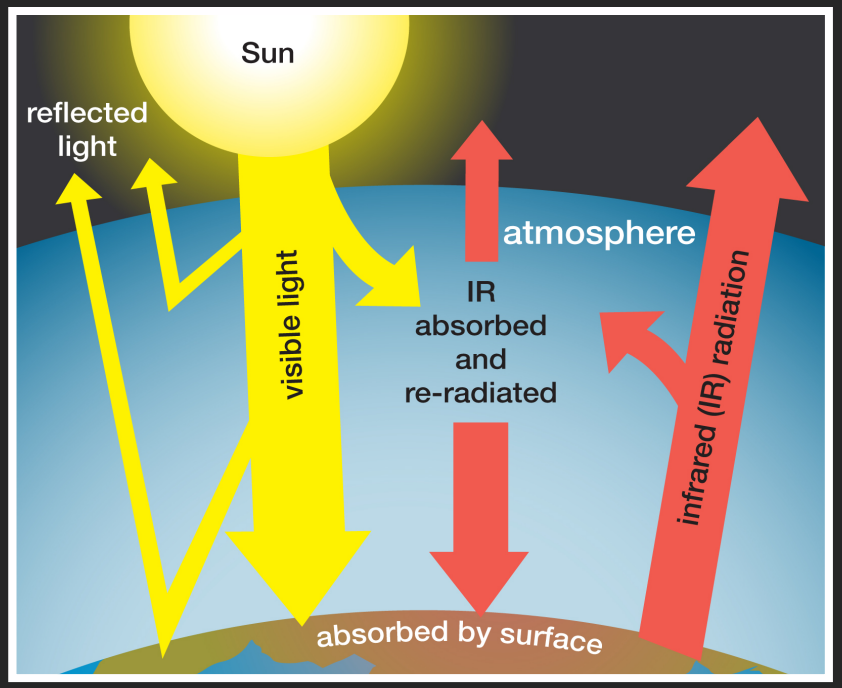
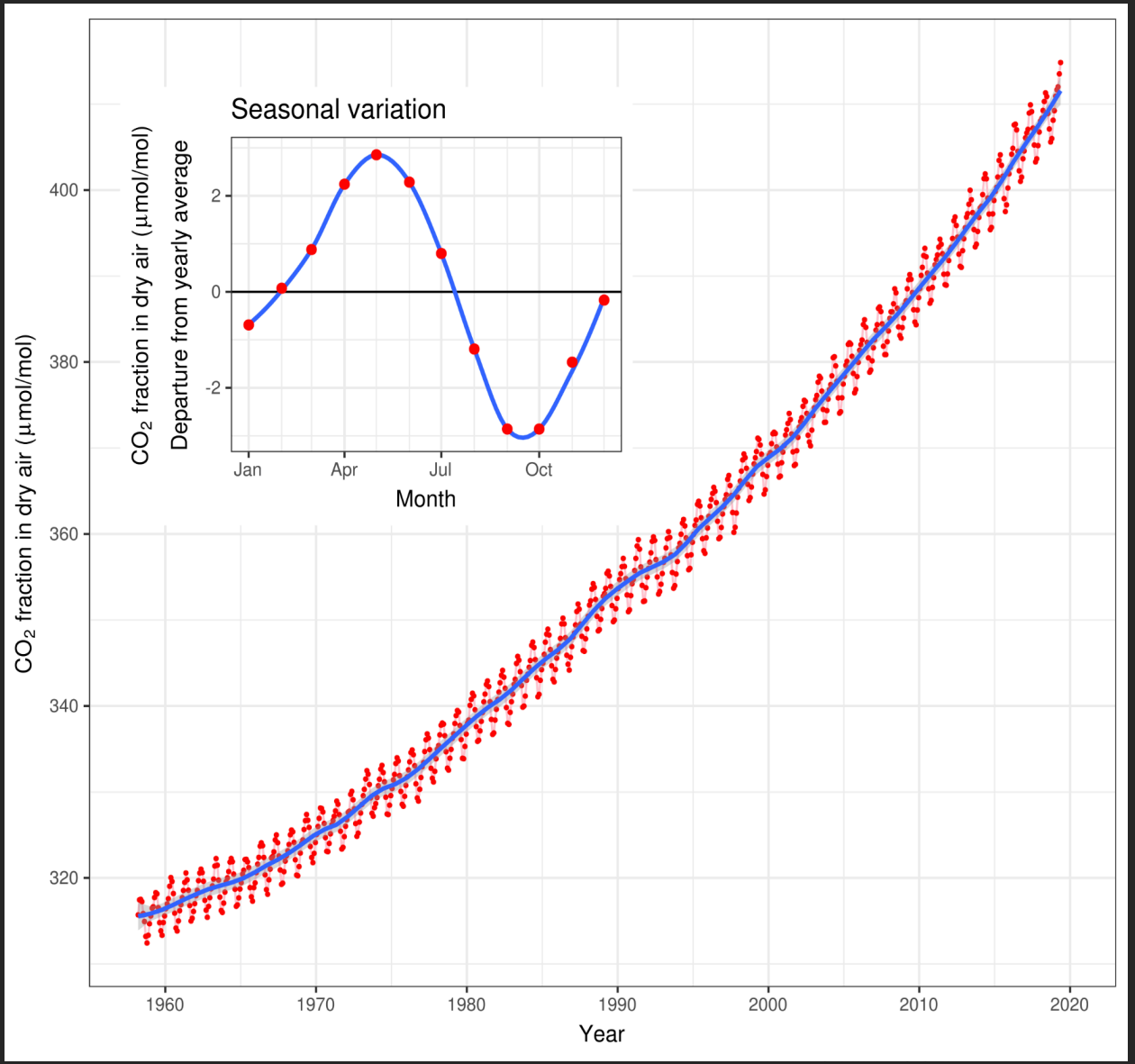
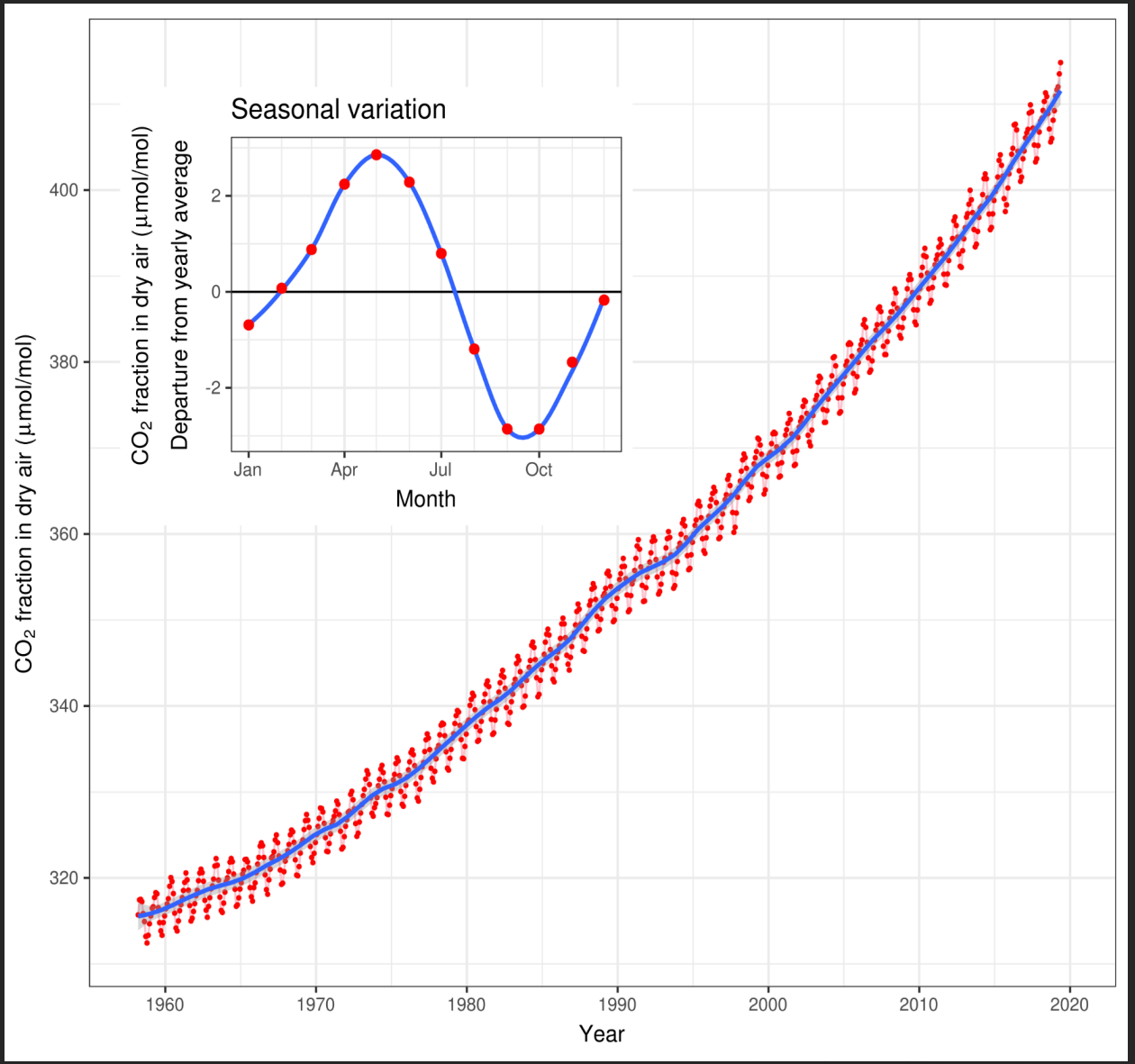
~ This ***natural***, and necessary for life, phenomenon is known as the ***greenhouse effect***, and ***water vapor*** and ***carbon dioxide*** as ***greenhouse gases***.





~ Because of the unchecked ***burning*** of ***fossil fuels***, CO_2 has rapidly ***increased***.



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~ The ***increased CO_2*** is ***warming*** the atmosphere and ***increasing*** the amount of ***water vapor*** the atmosphere can hold, potentially ***further increasing*** the ***greenhouse effect***.

~ *Clouds* act to both ***warm and cool*** the planet and are the ***subject*** of *debate* in the ***climate change community***.

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~ *Thick clouds reflect* radiation back into space, whereas *thin clouds transmit* radiation, which ***warms*** the ***Earth*** and then *traps longwave* radiation emitted.

Earth's energy budget

~ Apart from the warming due to increased greenhouse gases, the ***Earth's temperature*** remains relatively ***constant***, meaning there is a ***balance*** ***between incoming*** and ***outgoing*** energy.

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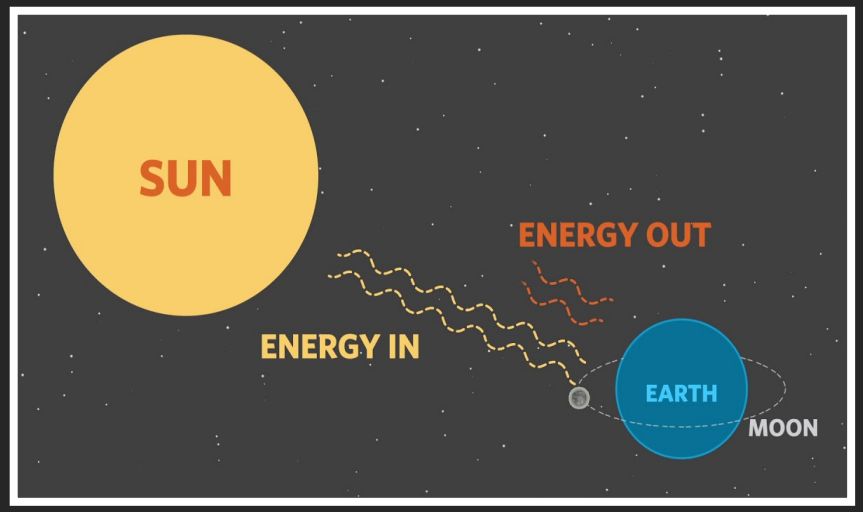

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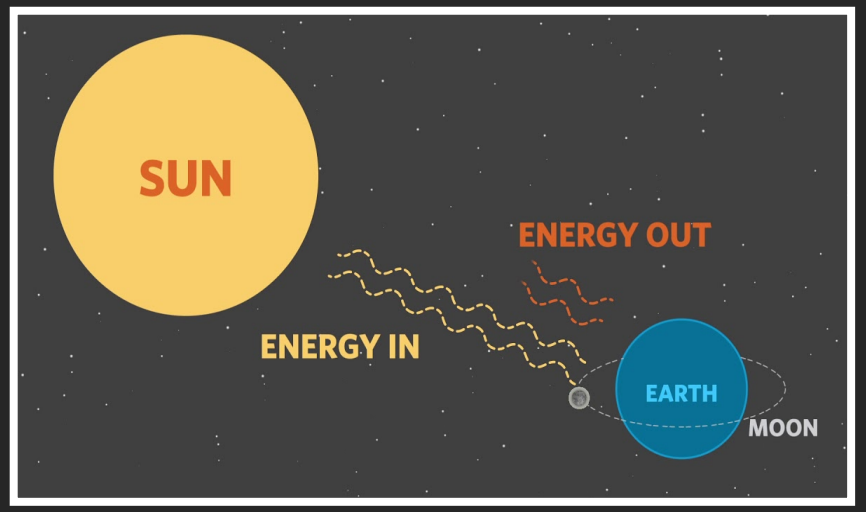

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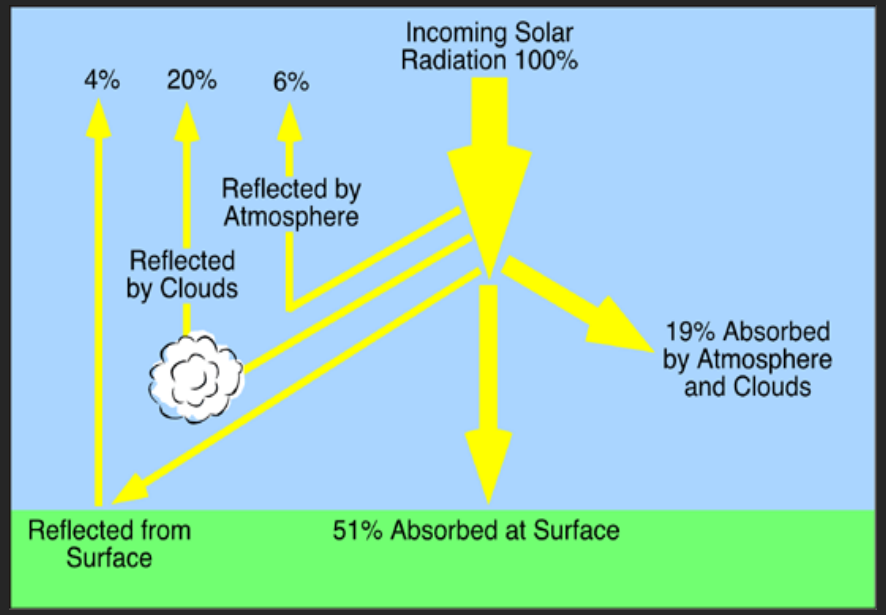
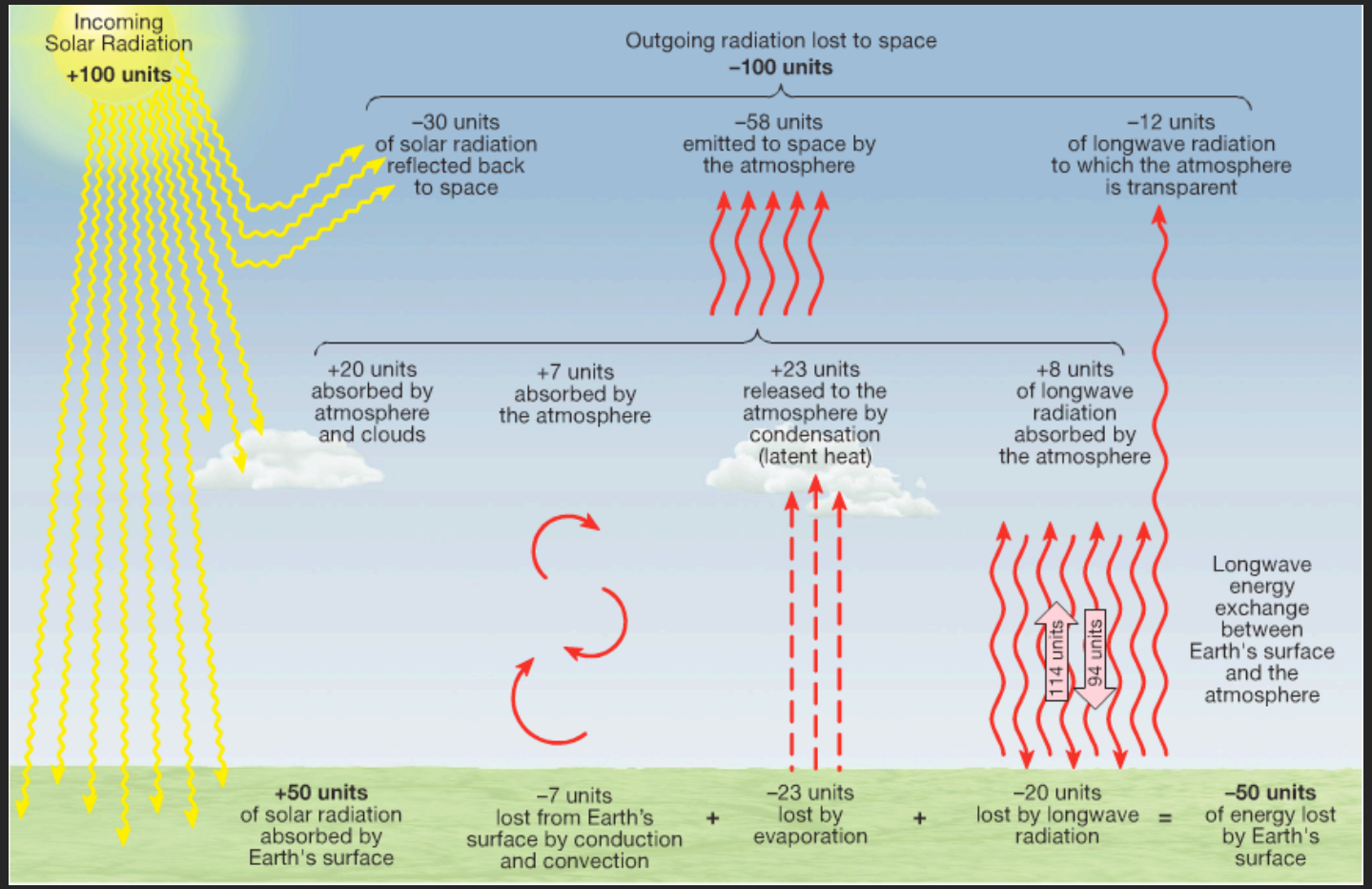
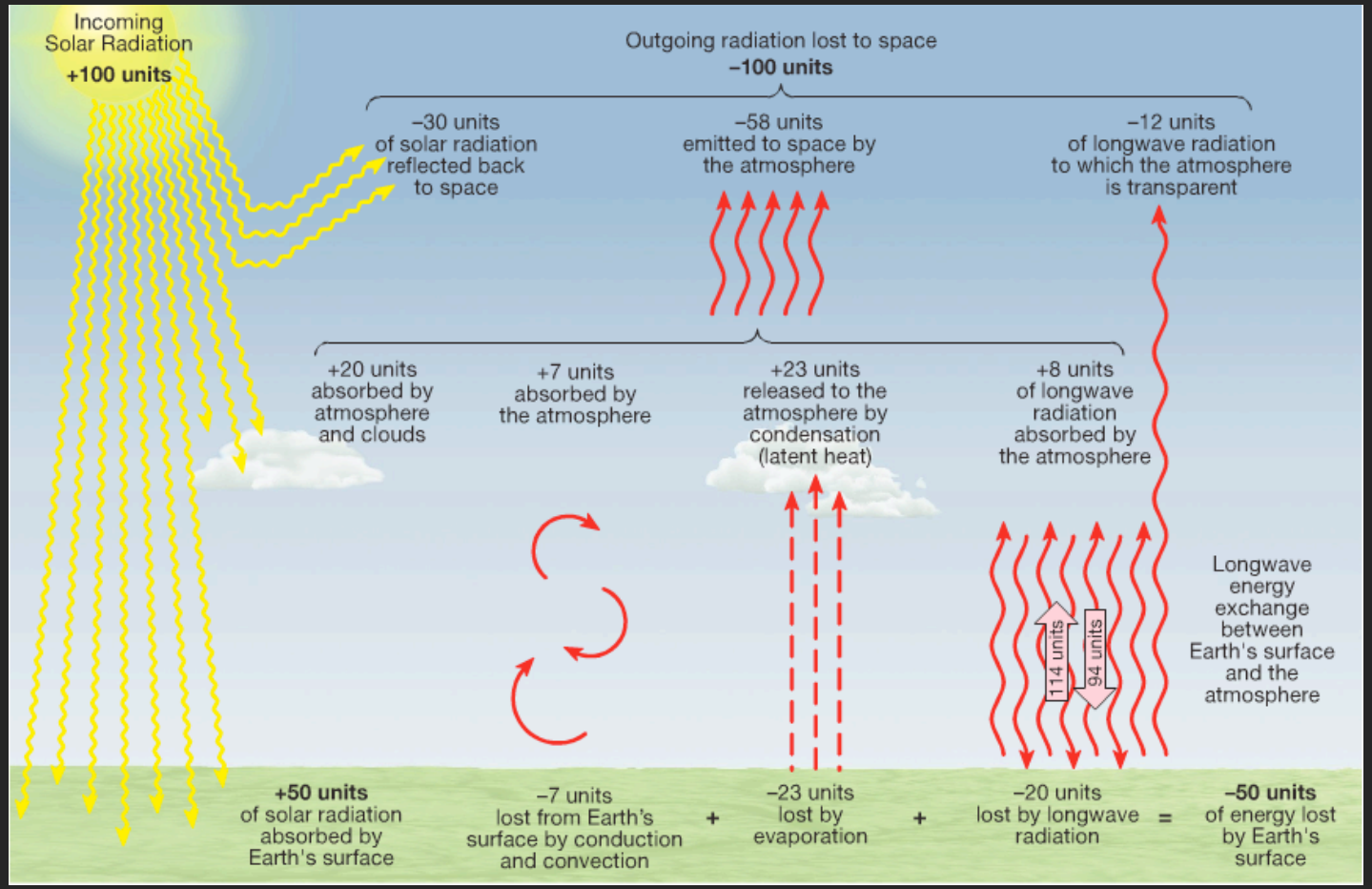
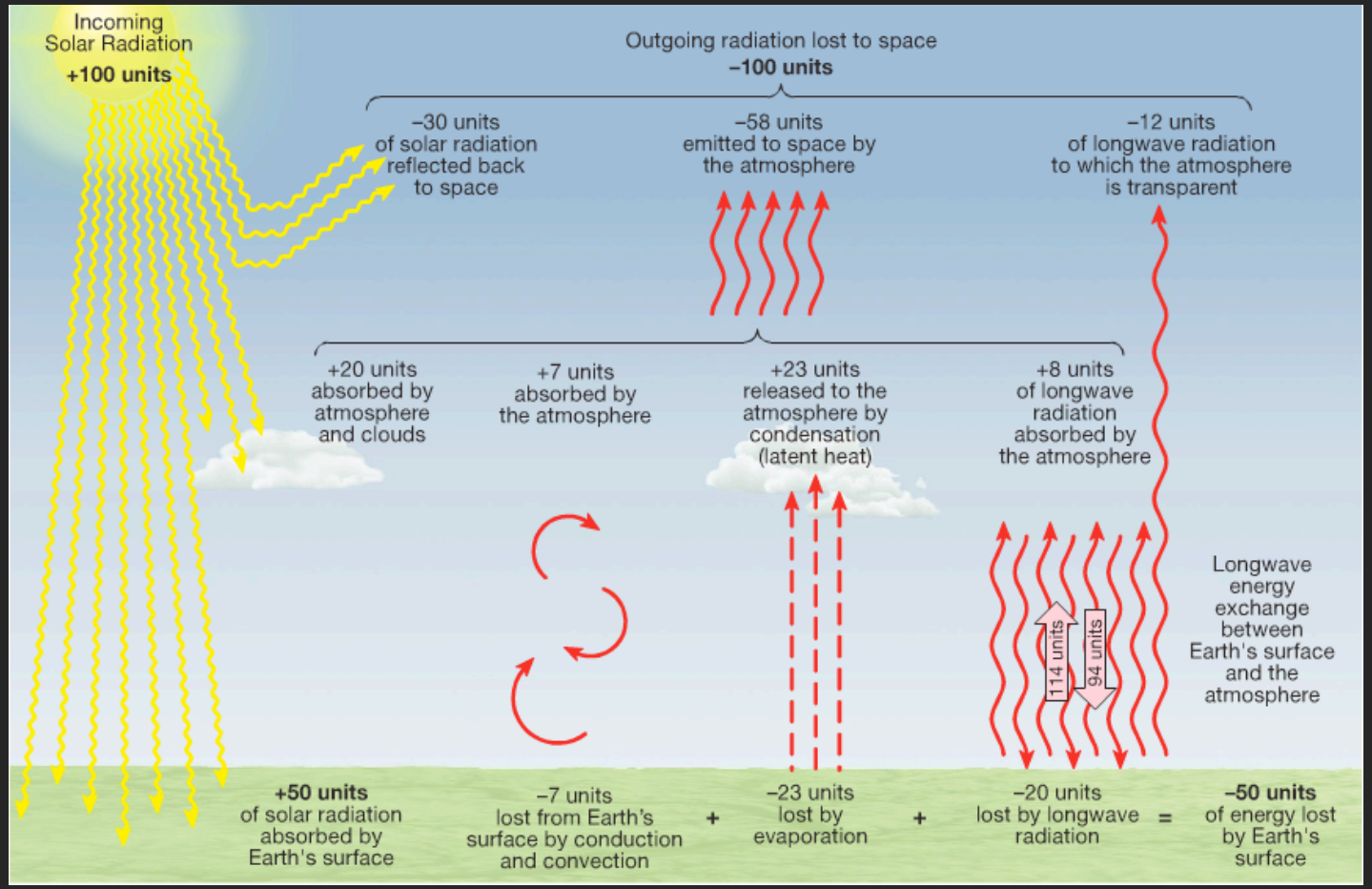


~ Recall, for every ***100 units*** of ***incoming*** solar radiation, ***30 units*** are ***reflected*** back into space, ***20 units*** are ***absorbed*** by ***clouds***, and ***50 units*** are ***absorbed*** by the ***surface***.

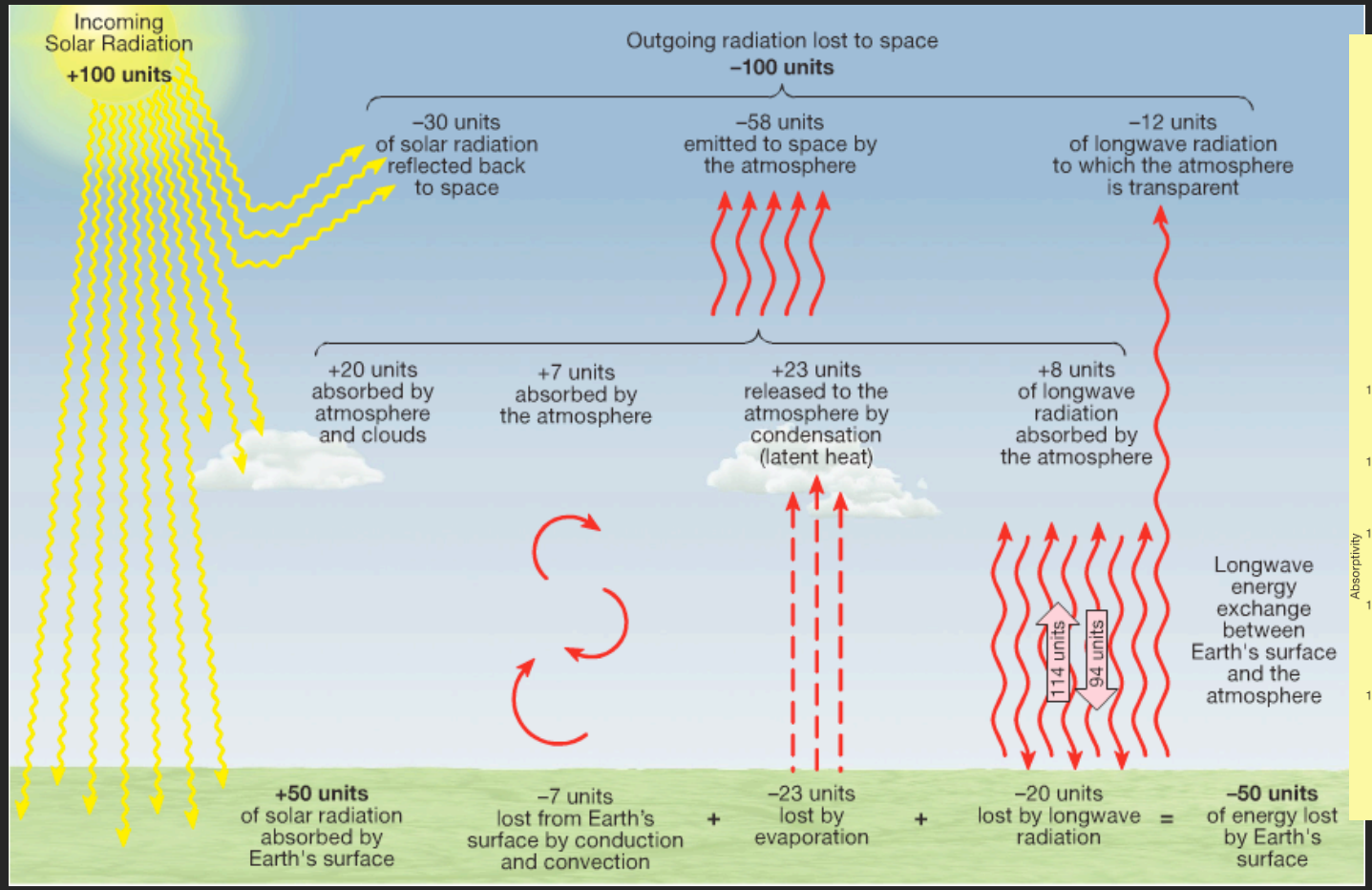

Incoming
Solar Radiation
+100 units
Outgoing radiation lost to space
−100 units
−30 units
of solar radiation
reflected back
to space
−58 units
emitted to space by
the atmosphere
−12 units
of longwave radiation
to which the atmosphere
is transparent
+20 units
absorbed by
atmosphere
and clouds
+7 units
absorbed by
the atmosphere
+23 units
released to the
atmosphere by
condensation
(latent heat)
+8 units
of longwave
radiation
absorbed by
the atmosphere
114 units
94 units
Longwave
energy
exchange
between
Earth's surface
and the
atmosphere
+50 units
of solar radiation
absorbed by
Earth's surface
−7 units
lost from Earth's
surface by conduction
and convection
+
−23 units
lost by
evaporation
+
−20 units
lost by longwave
radiation
=
−50 units
of energy lost
by Earth's
surface

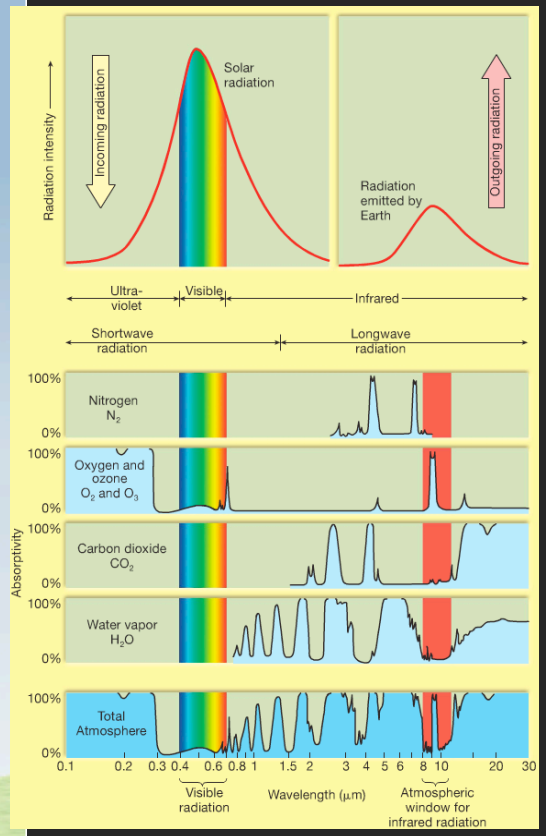


~ To ***keep*** the surface the ***same temperature***, it must lose (***re-emit***) ***50 units***, with ***20 units*** going to ***longwave*** radiation, ***23 units*** to ***evaporation***, and ***7 units*** to ***convection*** and ***conduction***.



~ For the ***Earth*** as a ***whole***, ***30 units*** are ***reflected*** immediately, so there are ***70 units*** to ***lose***: ***58 units*** are ***emitted*** to space by the ***atmosphere***, and ***12 units escape*** directly from the ground through the "***atmospheric window***".





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Latitudinal heat balance

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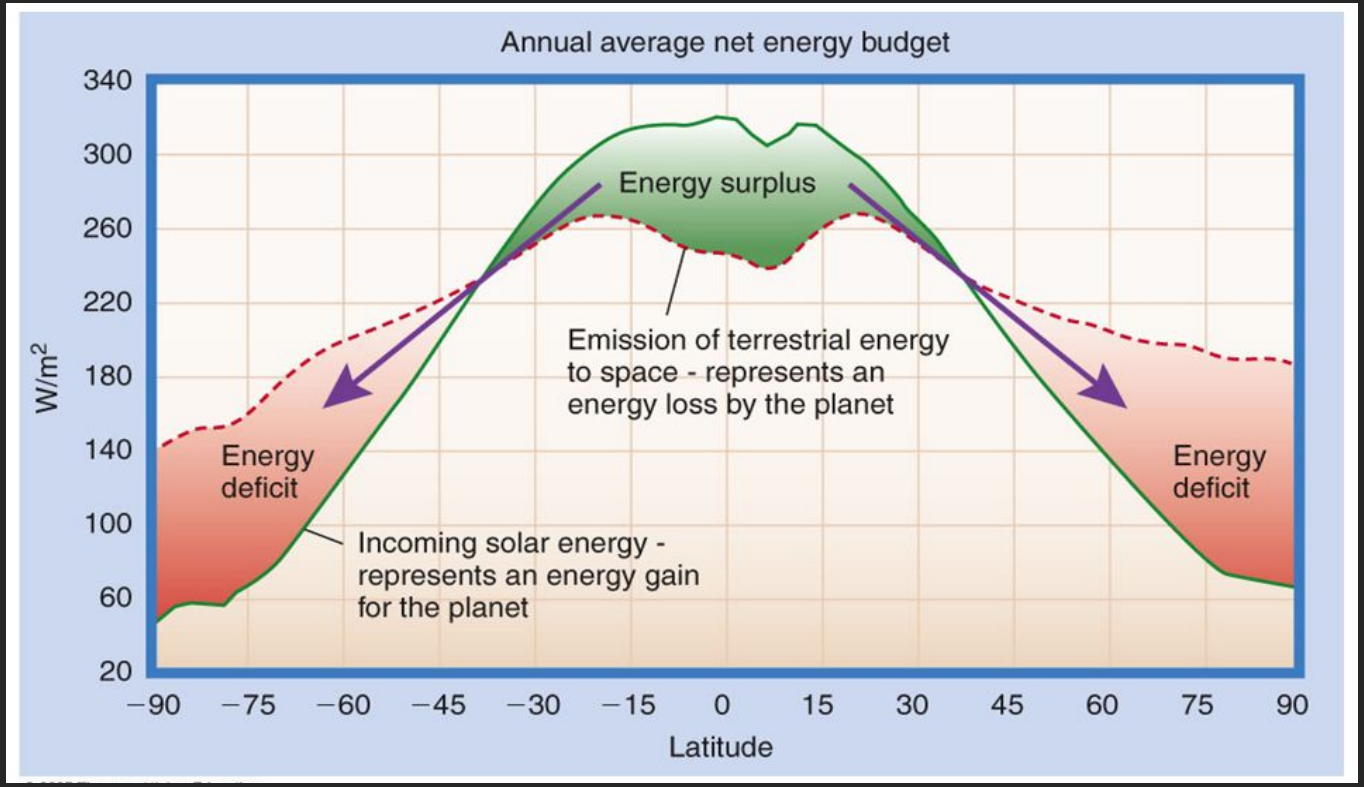

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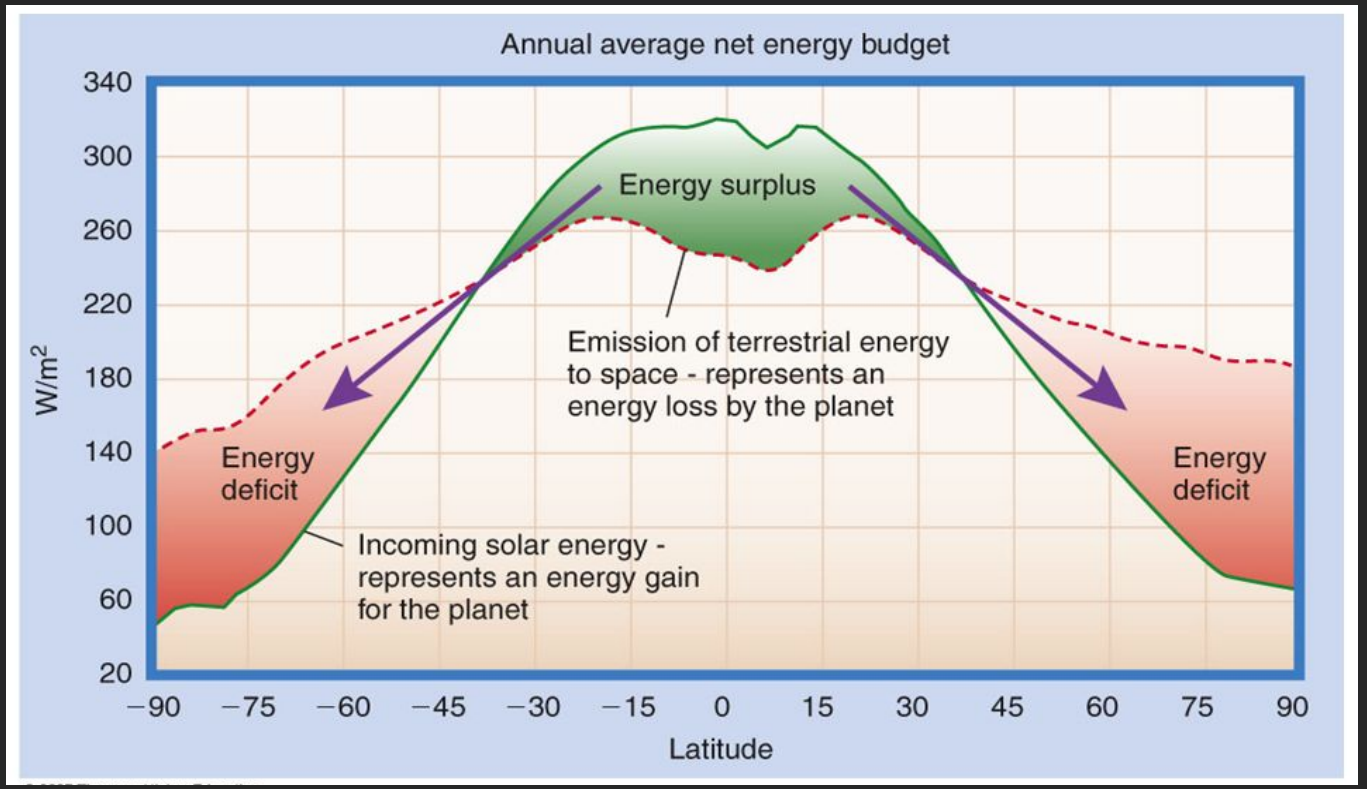

~ The ***tropics*** receive ***more*** solar ***radiation*** ***than*** is ***lost*** to space, while the ***polar*** regions ***lose more*** radiation ***than*** is ***received***.

~ The ***radiation balance*** (and the ***temperature***) of a location ***varies with cloud cover***, atmospheric ***composition***, and most important, ***Sun angle***.

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