Solar Energy: The Sun to Earth Transaction

Learning objectives:

1) To calculate the energy received by the Earth from the Sun
2) To compare the energy received by Earth from the Sun, with the energy usage by humankind

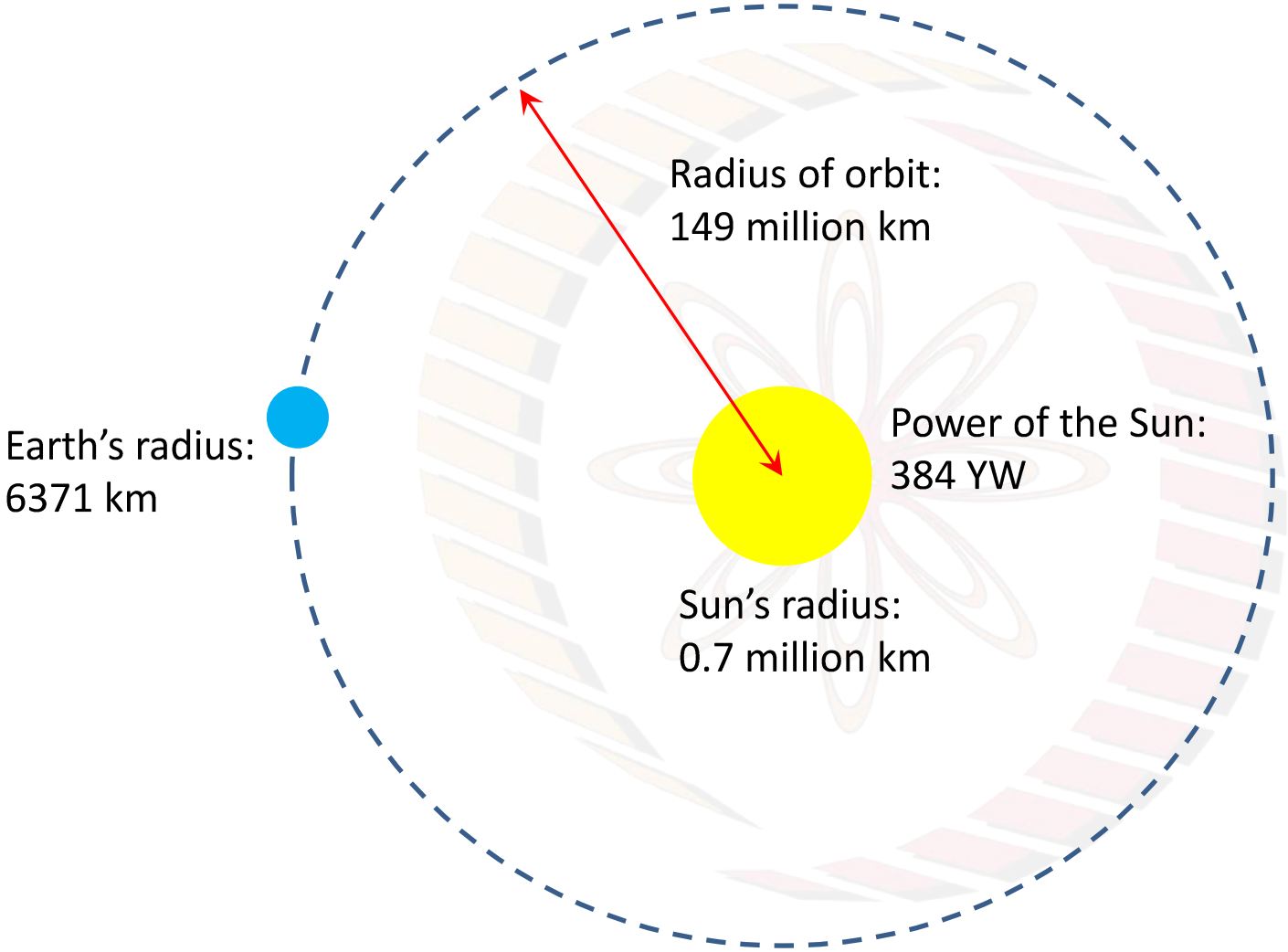
Surface of the Sun ~ 5500 ^{o}C

Core of the Sun, several million ^{o}C

Sun gives out 384 Yotta Watts

$= 384 \times 10^{24}$ W

$= 3.84 \times 10^{26}$ W

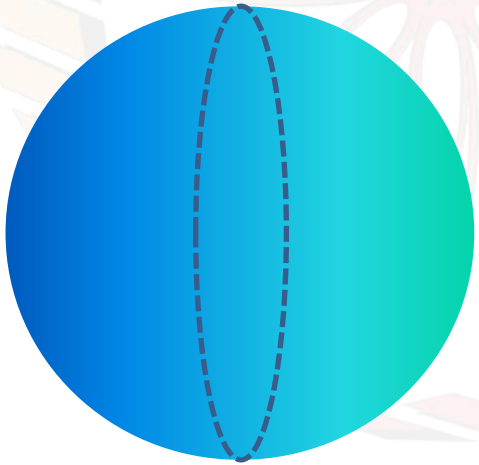

Radius of orbit:
149 million km
Earth’s radius:
6371 km
Power of the Sun:
384 YW
Sun’s radius:
0.7 million km

Intensity of Sun's radiation at Earth's orbit:

$$= \frac{3.84 \times 10^{26}}{4 \times 3.14 \times (1.49 \times 10^{11})^2} = 1377 \text{ W/m}^2$$

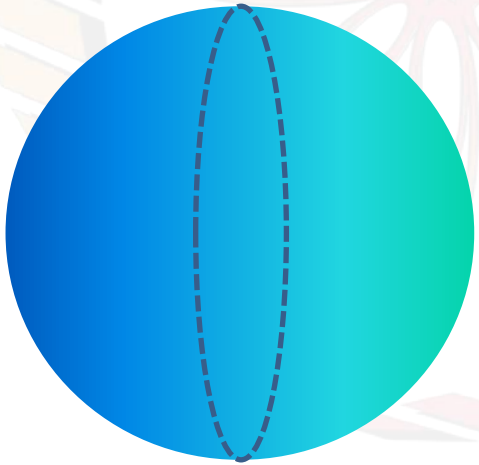
Area of Earth's disc:

$= \quad 3.14 \text{ X } (6.371 \text{ X } 10^{6})^{2} \quad = 1.27 \text{ X } 10^{14} \text{ m}^{2}$



Power received from the Sun, by Earth:

$= 1.27 \text{ X } 10^{14} \text{ X } 1377 = 1.755 \text{ X } 10^{17} \text{ W or J/s}$



Energy received from the Sun, by Earth each year:

$$= 1.755 \text{ X } 10^{17} \text{ X } 60 \text{ X } 60 \text{ X } 24 \text{ X } 365$$

$$= 5.5 \text{ X } 10^{24} \text{ J}$$

= 5.5 million Exa Joules per year

Humankind uses:

= 500 Exa Joules per year

Earth receives from the Sun:

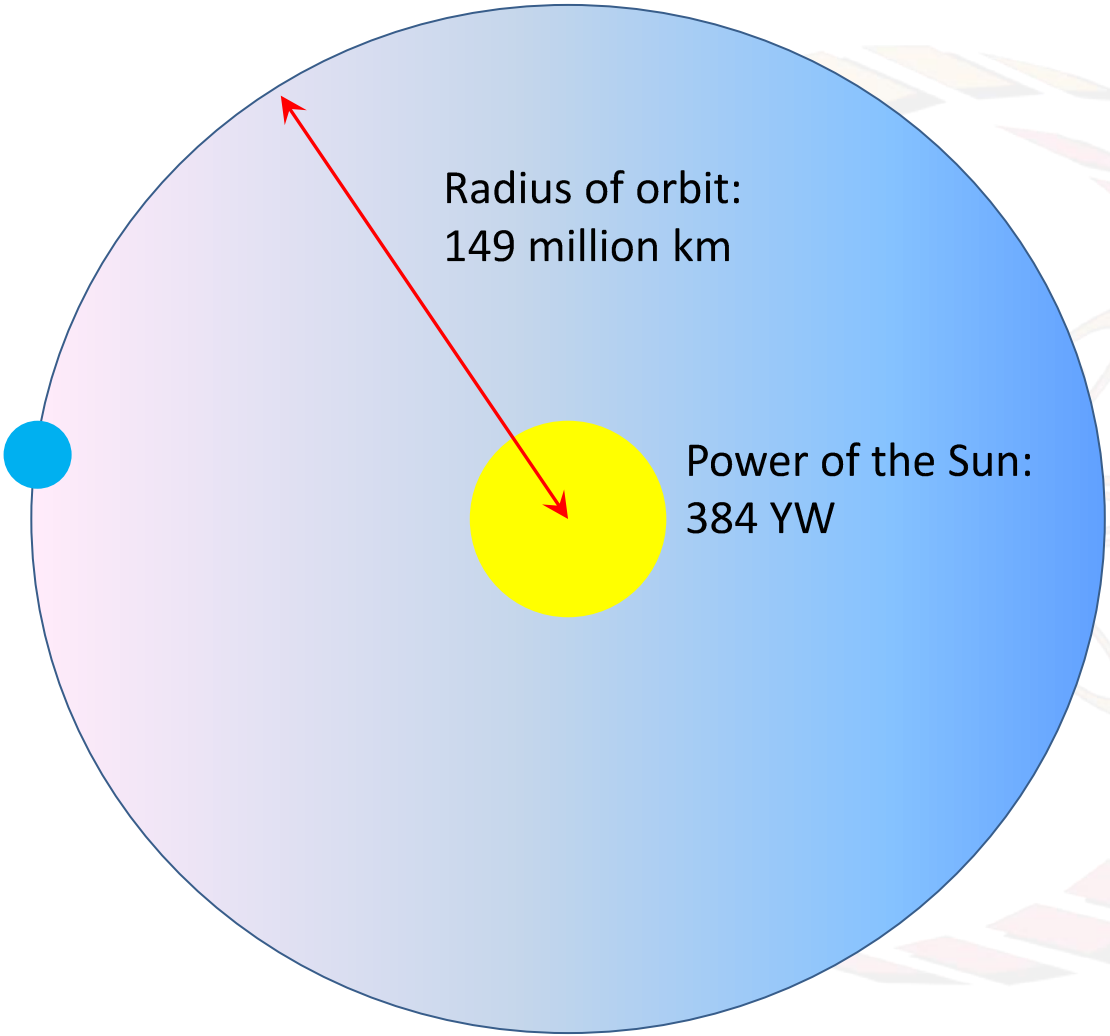
5.5 million Exa Joules per year

This is received in :

$500 / 5.5 \times 10^{6} = 9 \times 10^{-5}$ years = 0.033 days = 0.79 hours

Since 30% of the incident energy is reflected back, on the surface of the Earth, the energy used by humankind each year is received in :

$$= 0.79/0.70 \sim \textbf{1 hour}$$



Dyson Sphere:
Freeman Dyson (1960)

Kardashev Scale (1964)
Type 1: All energy reaching planet
Type 2: All energy of Star
Type 3: All energy of Galaxy

Conclusions:

1) Earth receives nearly 5.5 million exa joules of energy from the Sun each year
2) The entire energy used by humankind each year, is received on the surface of the earth, from the sun, each hour!

The Solar Energy Budget

Learning objectives:

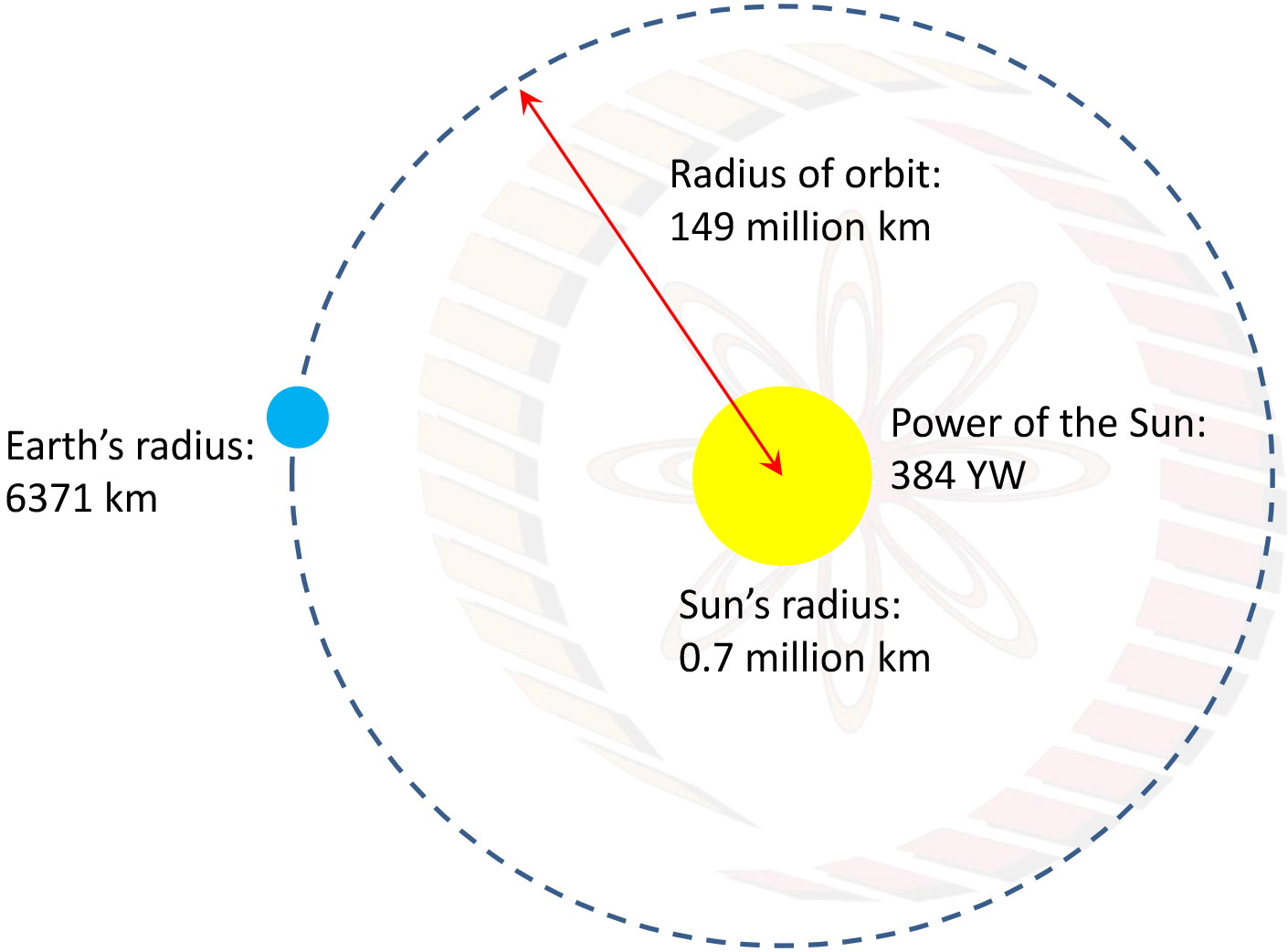
1) To know how incoming solar energy is distributed across various phenomena on earth
2) To become aware of geographical and seasonal aspects associated with solar energy
3) To become aware of impact of time of day on ability to receive solar energy

Layers of the atmosphere:

Exosphere:	700 to 10,000 km
Thermosphere:	80 to 700 km
Mesosphere:	50 to 80 km
Stratosphere:	12 to 50 km
Troposphere:	0 to 12 km

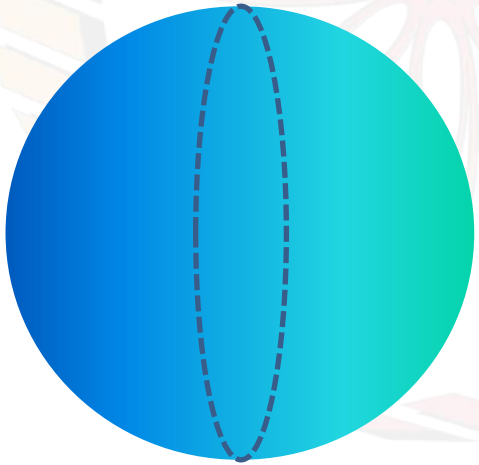
Approximately 80% of mass of Earth's atmosphere is in the Troposphere

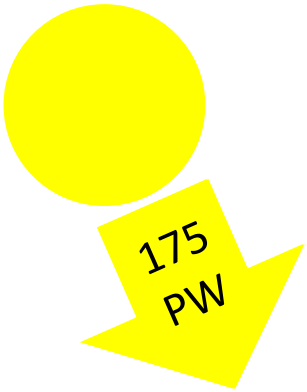
Source: https://en.wikipedia.org/wiki/Atmosphere_of_Earth

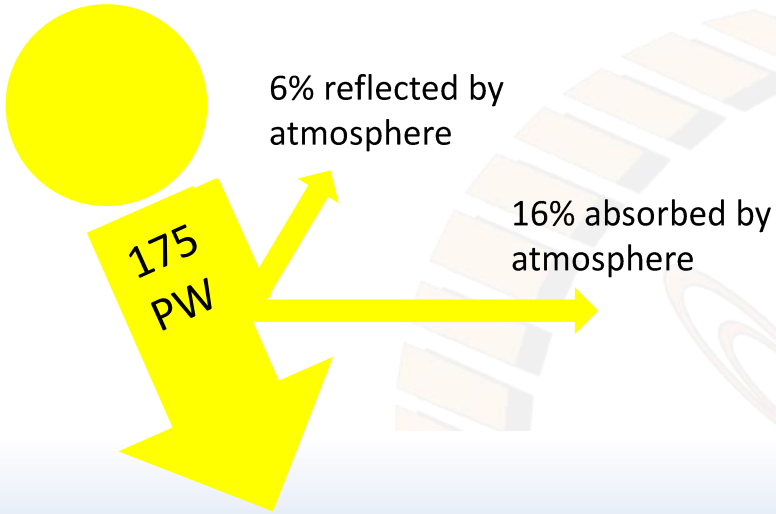

Radius of orbit:
149 million km
Earth’s radius:
6371 km
Power of the Sun:
384 YW
Sun’s radius:
0.7 million km

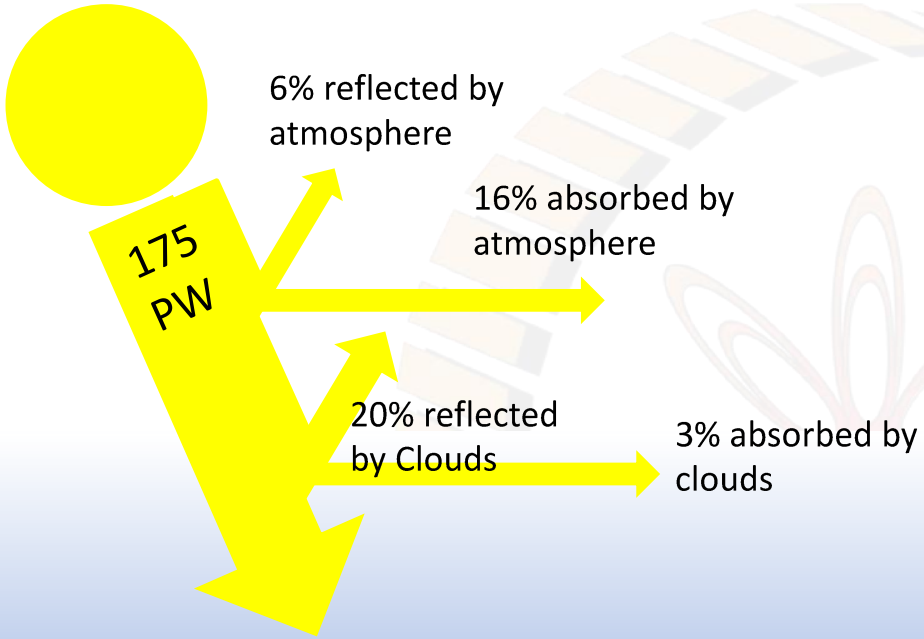
Power received from the Sun, by Earth:

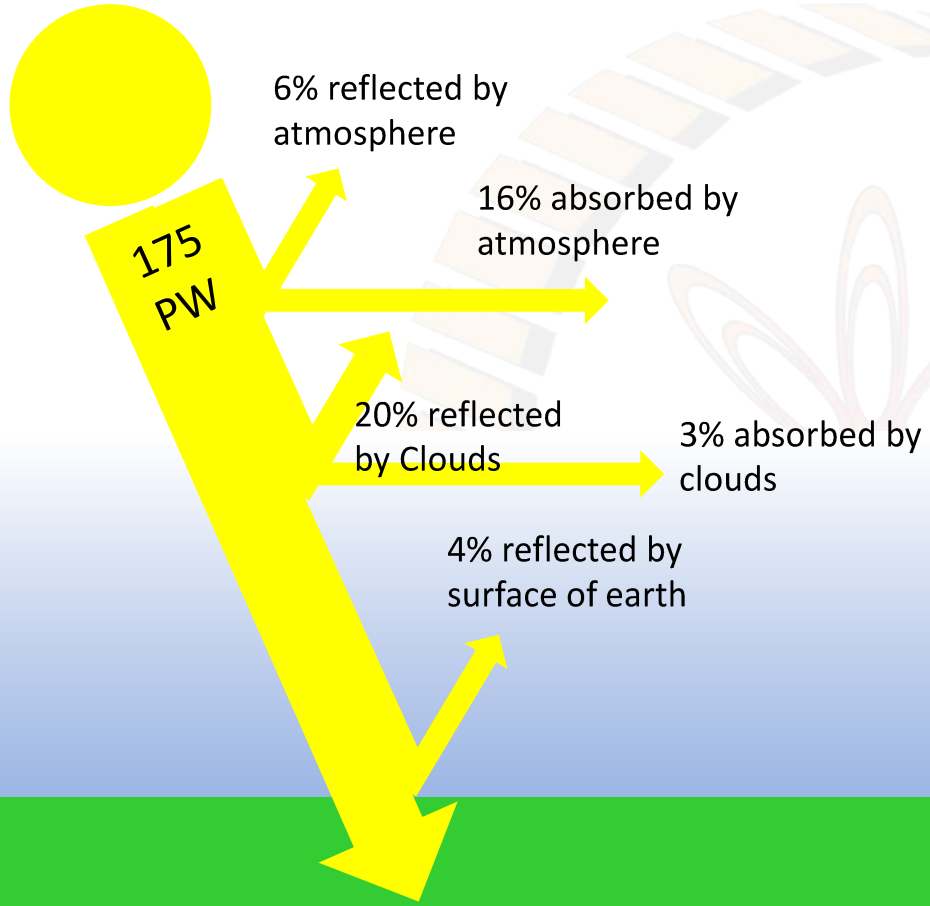
$= 1.27 \text{ X } 10^{14} \text{ X } 1377 = 1.755 \text{ X } 10^{17} \text{ W or J/s}$

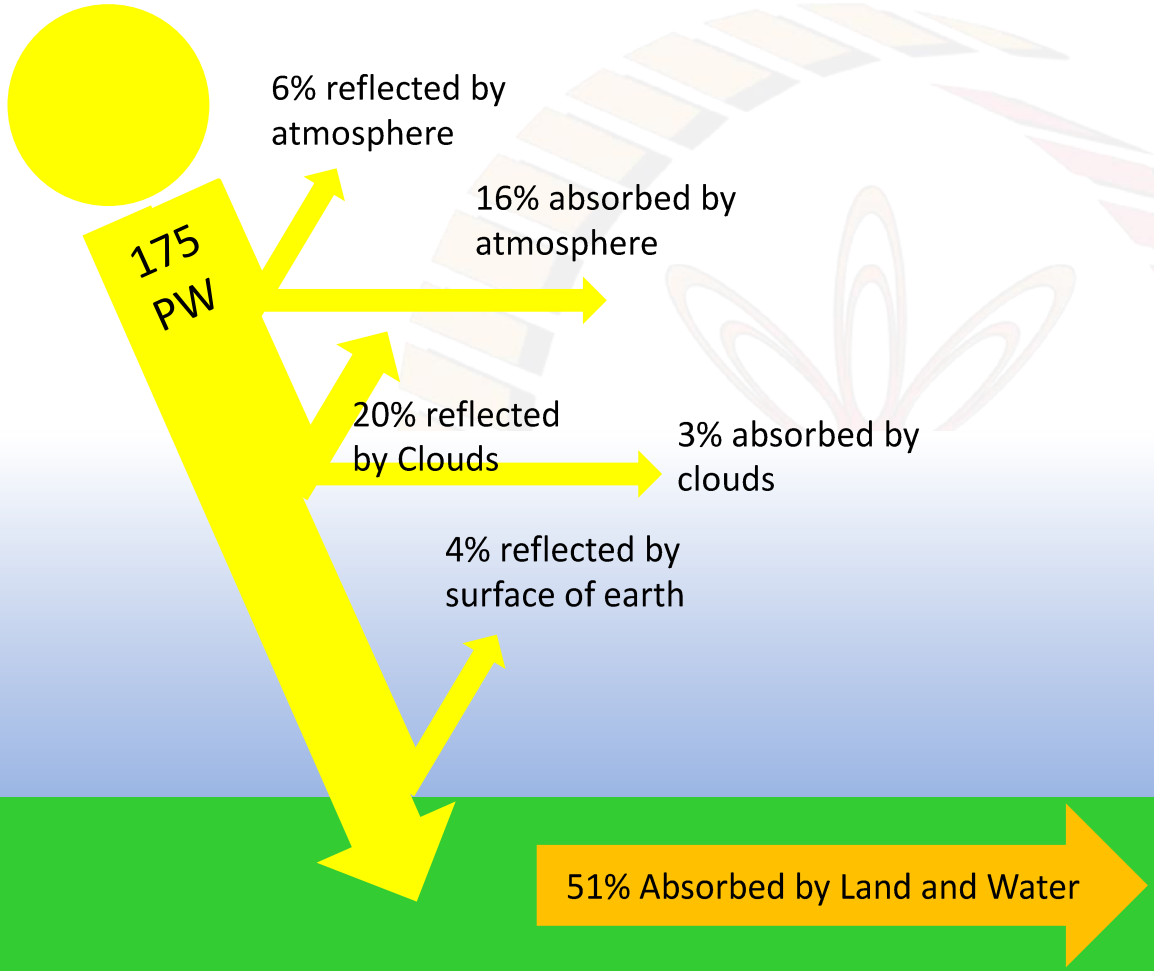


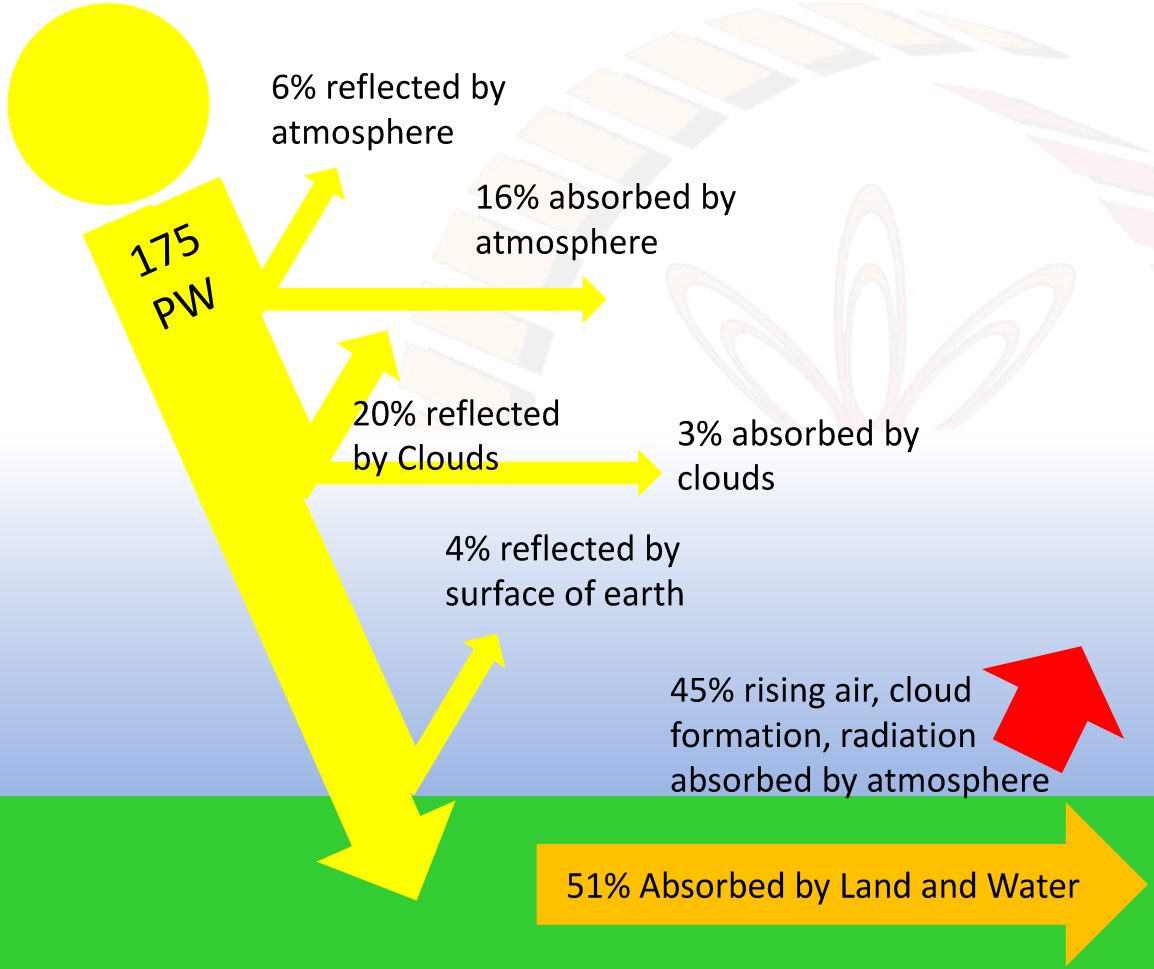

175
PW

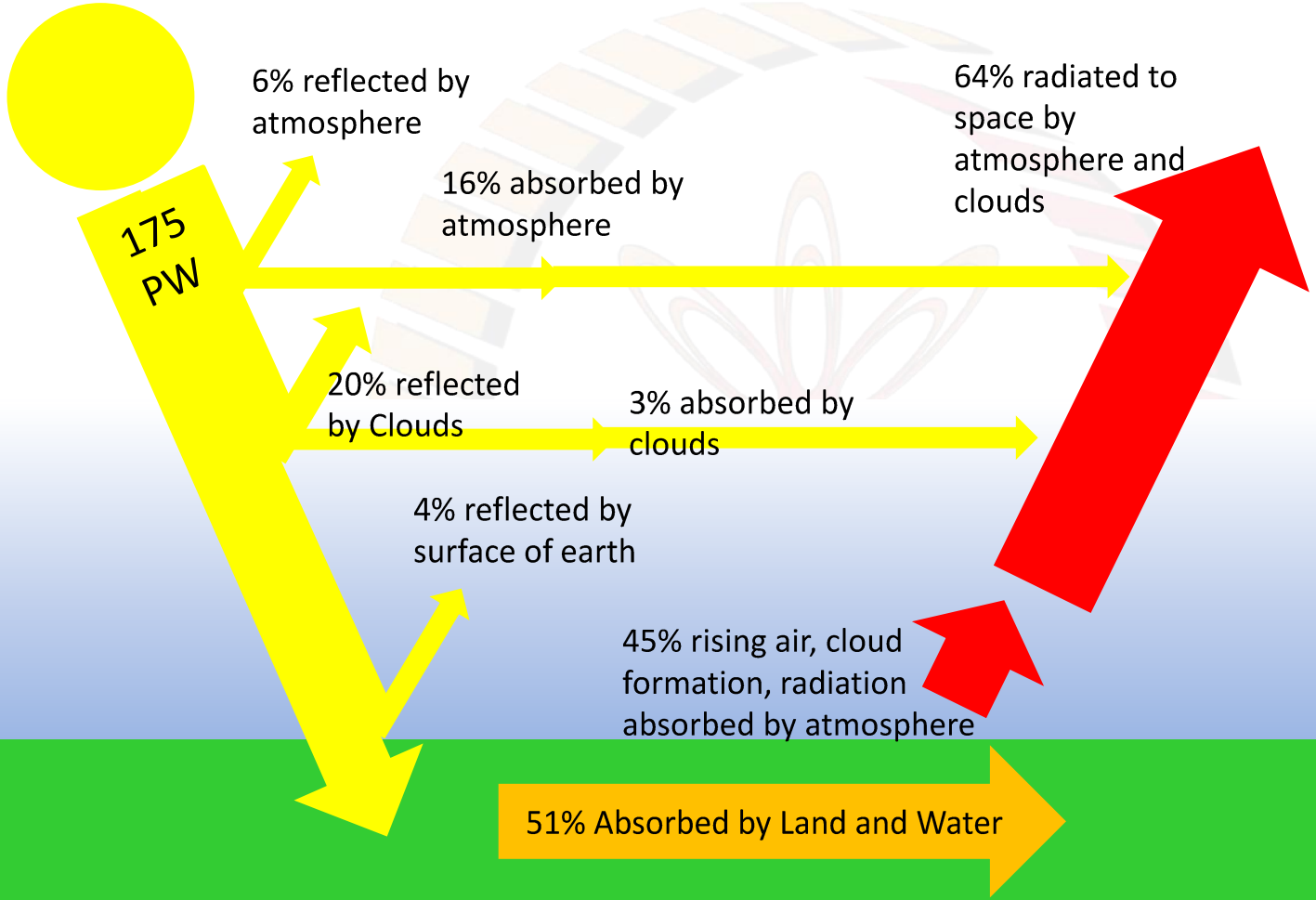

6% reflected by atmosphere
16% absorbed by atmosphere
175 PW

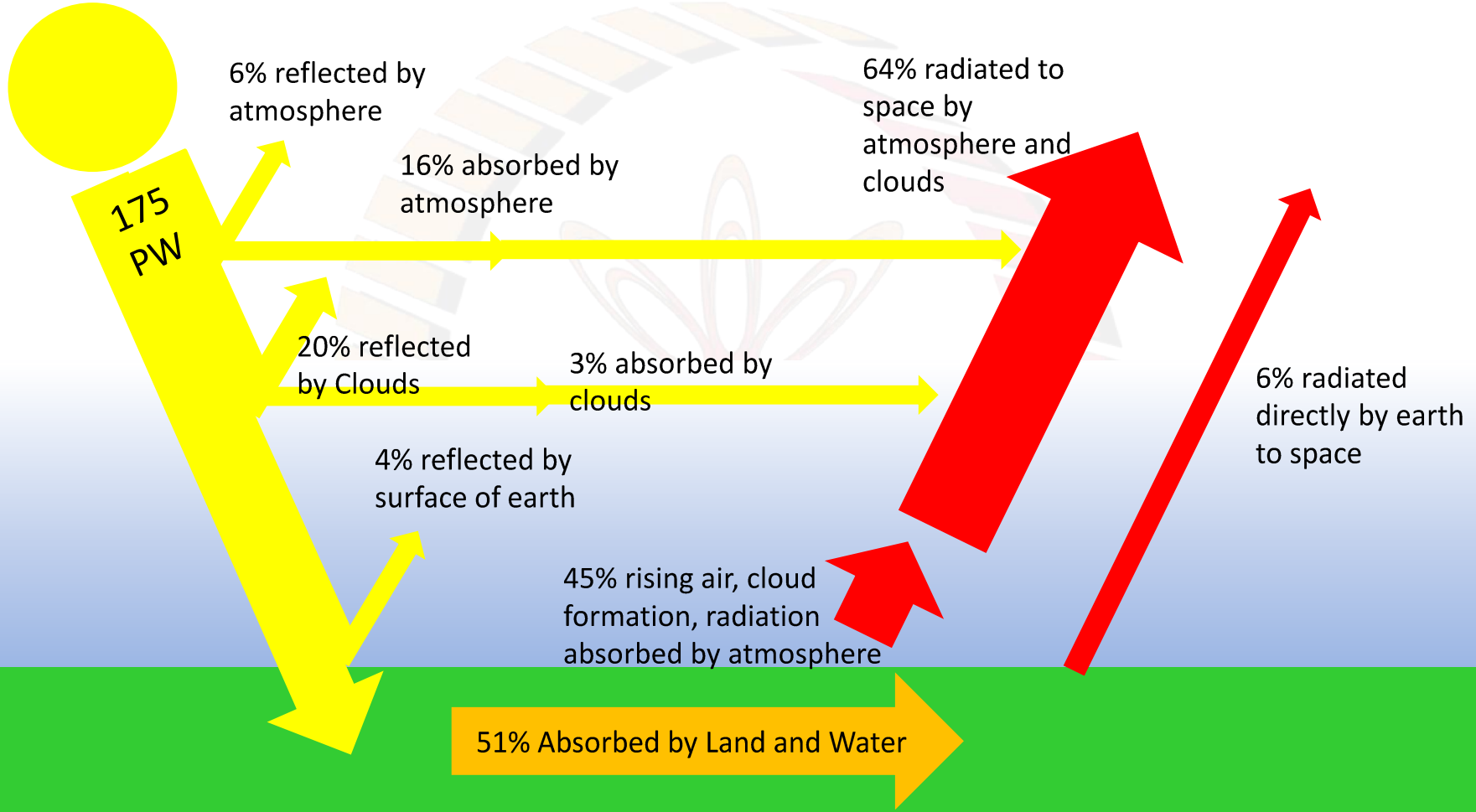

6% reflected by atmosphere
16% absorbed by atmosphere
175 PW
20% reflected by Clouds
3% absorbed by clouds

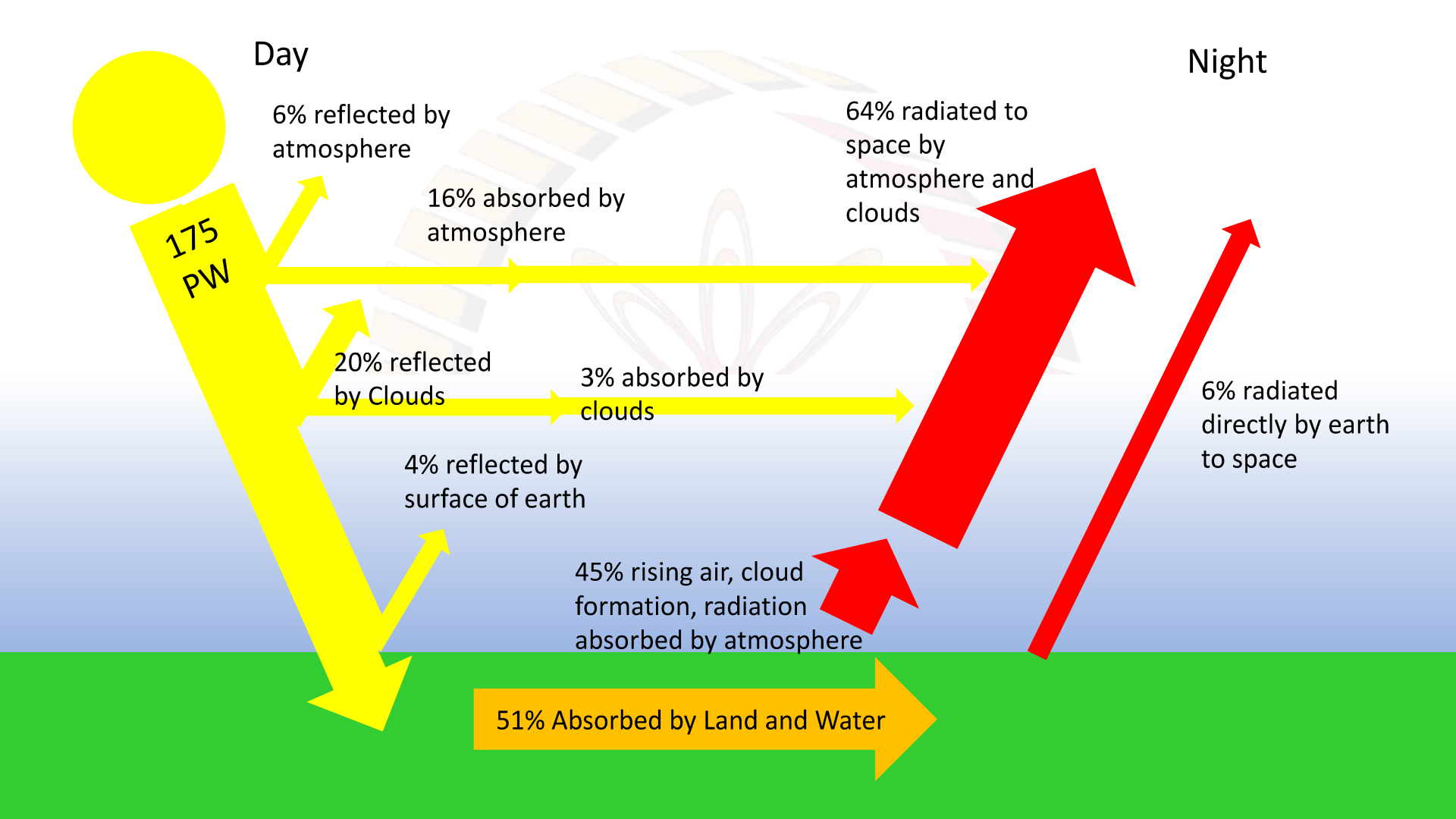

175 PW
6% reflected by atmosphere
16% absorbed by atmosphere
20% reflected by Clouds
3% absorbed by clouds
4% reflected by surface of earth

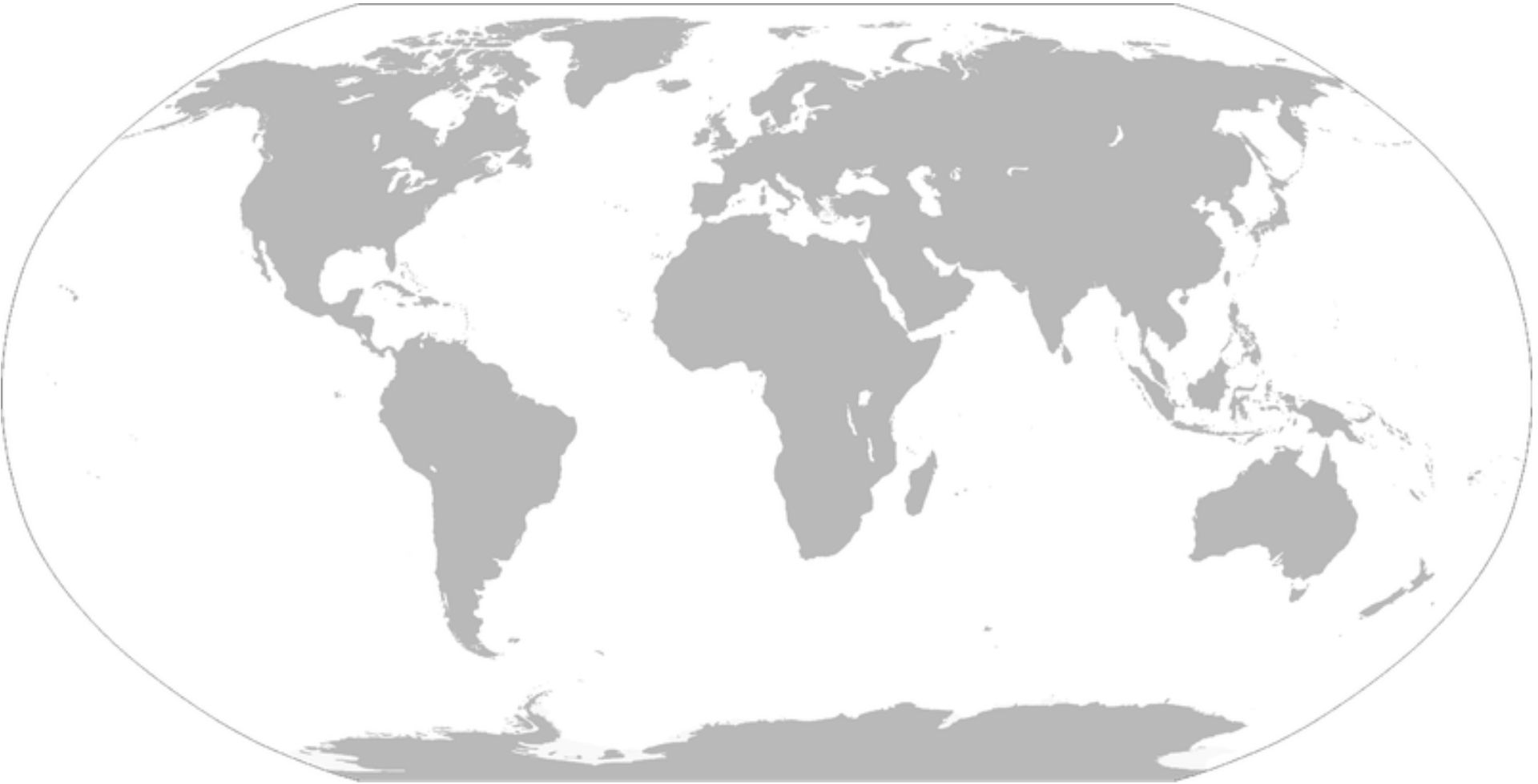

6% reflected by atmosphere
16% absorbed by atmosphere
175 PW
20% reflected by Clouds
3% absorbed by clouds
4% reflected by surface of earth
51% Absorbed by Land and Water


6% reflected by atmosphere
16% absorbed by atmosphere
175 PW
20% reflected by Clouds
3% absorbed by clouds
4% reflected by surface of earth
45% rising air, cloud formation, radiation absorbed by atmosphere
51% Absorbed by Land and Water


6% reflected by atmosphere
64% radiated to space by atmosphere and clouds
16% absorbed by atmosphere
175 PW
20% reflected by Clouds
3% absorbed by clouds
4% reflected by surface of earth
45% rising air, cloud formation, radiation absorbed by atmosphere
51% Absorbed by Land and Water

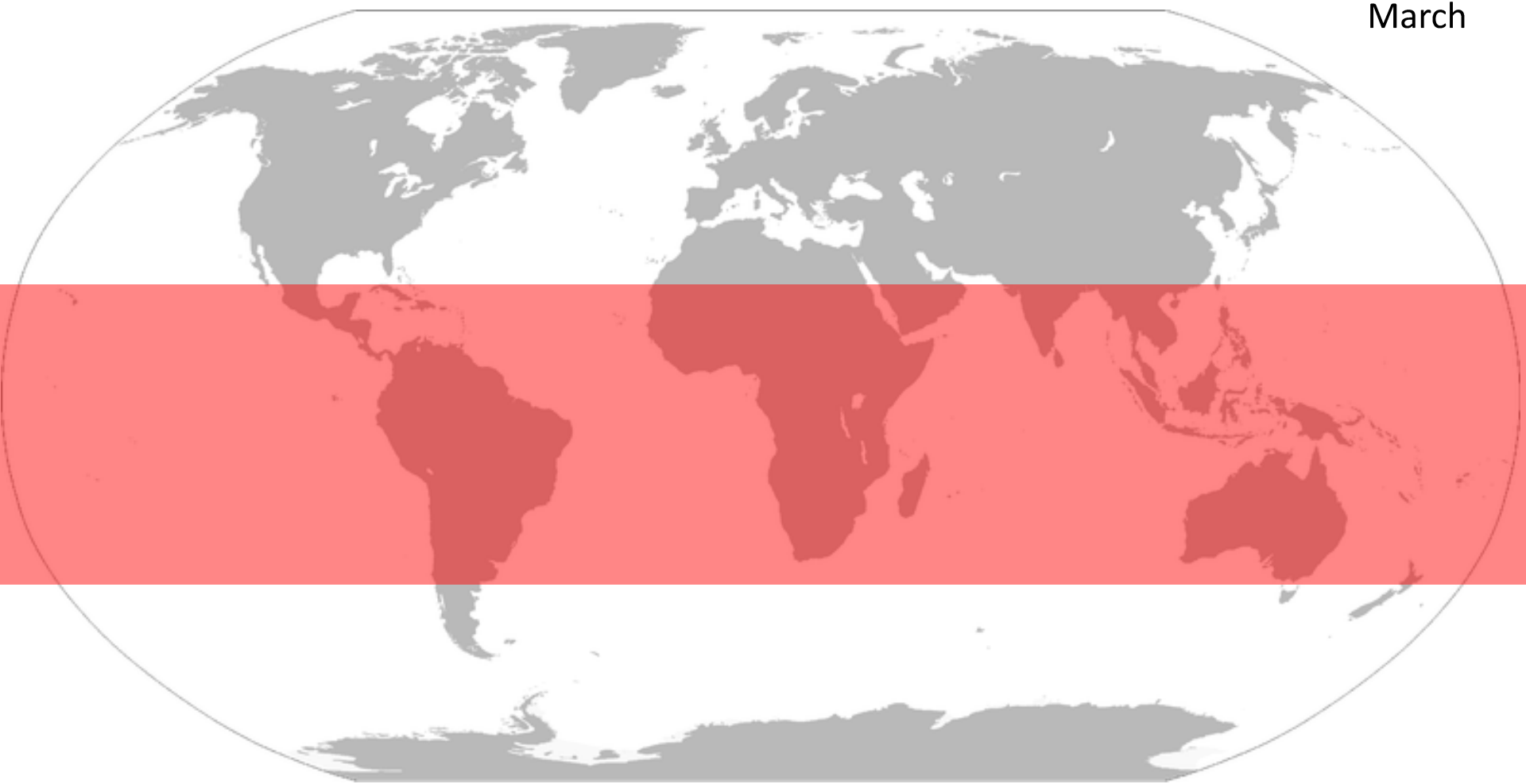

175 PW
6% reflected by atmosphere
16% absorbed by atmosphere
64% radiated to space by atmosphere and clouds
20% reflected by Clouds
3% absorbed by clouds
6% radiated directly by earth to space
4% reflected by surface of earth
45% rising air, cloud formation, radiation absorbed by atmosphere
51% Absorbed by Land and Water


Day
Night
6% reflected by atmosphere
16% absorbed by atmosphere
64% radiated to space by atmosphere and clouds
175 PW
20% reflected by Clouds
3% absorbed by clouds
6% radiated directly by earth to space
4% reflected by surface of earth
45% rising air, cloud formation, radiation absorbed by atmosphere
51% Absorbed by Land and Water



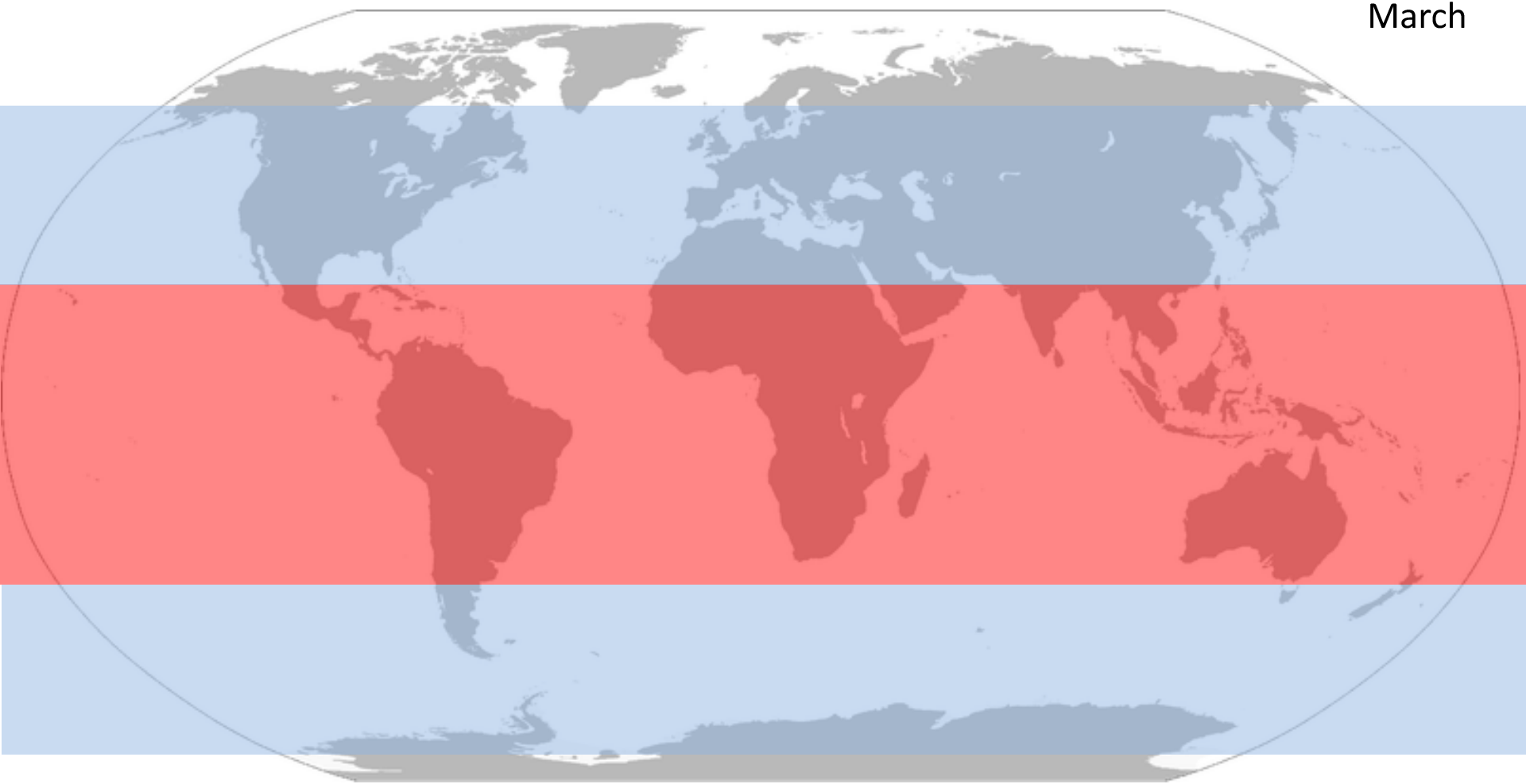
https://en.wikipedia.org/wiki/File:BlankMap-World-large-noborders.png

March

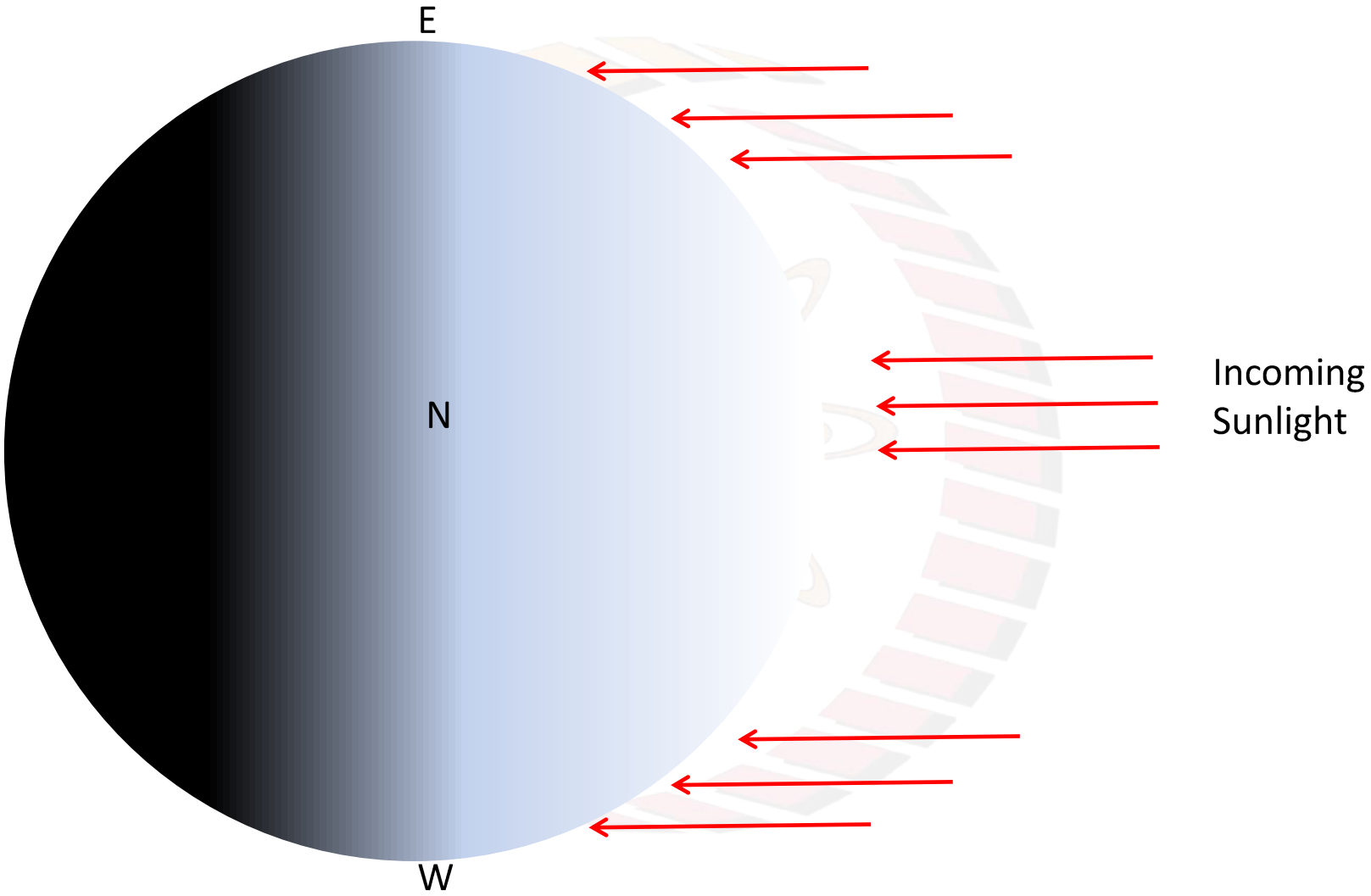


https://en.wikipedia.org/wiki/File:BlankMap-World-large-noborders.png

March



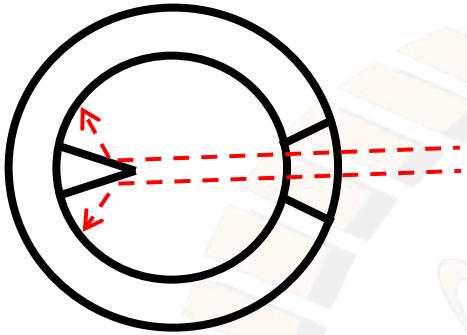
https://en.wikipedia.org/wiki/File:BlankMap-World-large-noborders.png


E
N
W
Incoming
Sunlight

Conclusions:

1) Solar energy is absorbed and released through a wide range of phenomena on earth
2) Geographical location and seasons are important aspects impacting solar energy received by specific locations
3) Time of the day is an important parameter impacting the intensity of solar energy received

The Solar Spectrum

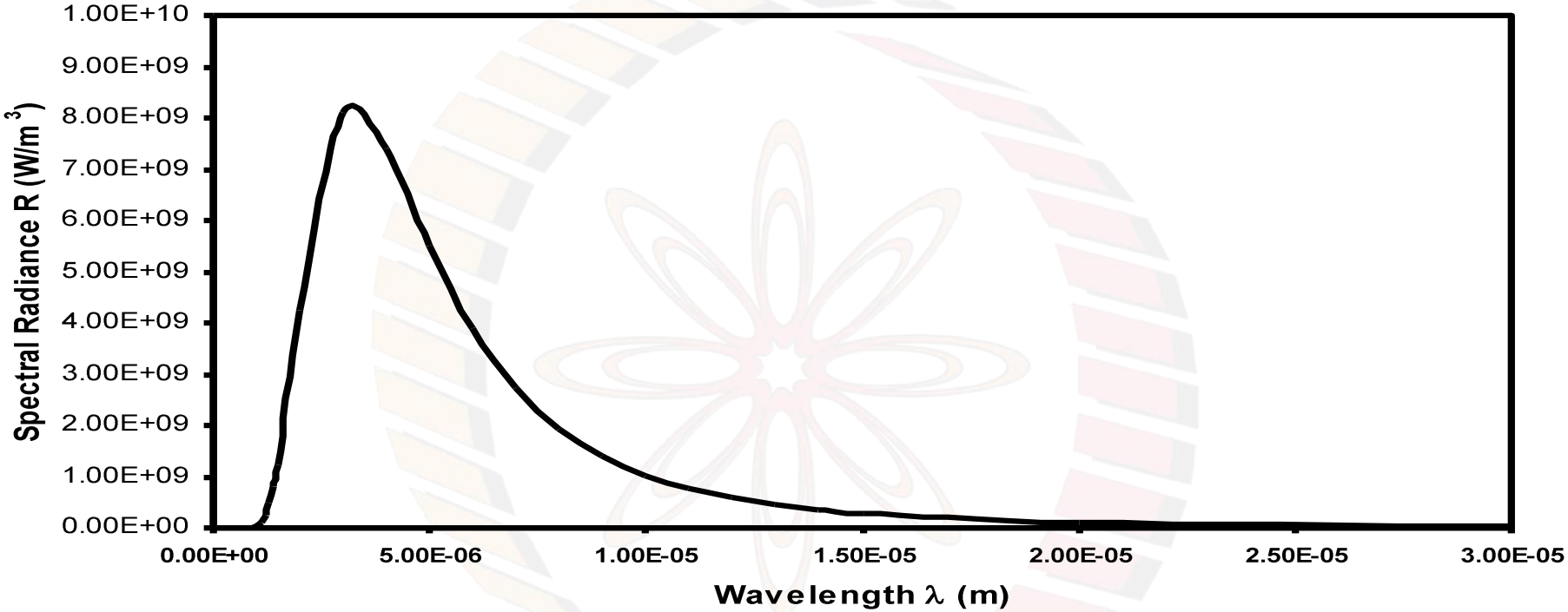


Kirchoff designed a black body in 1859

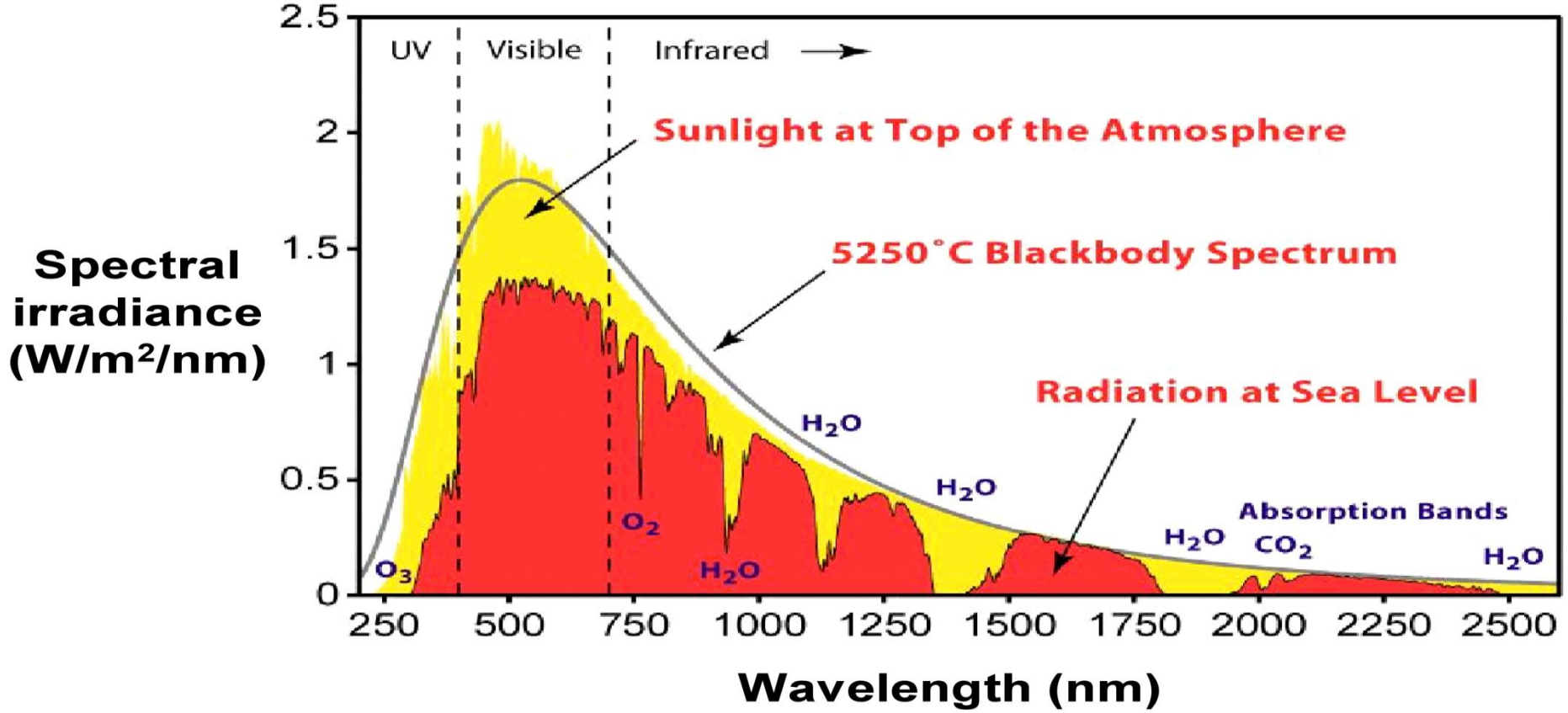
Known properties of black body radiation:

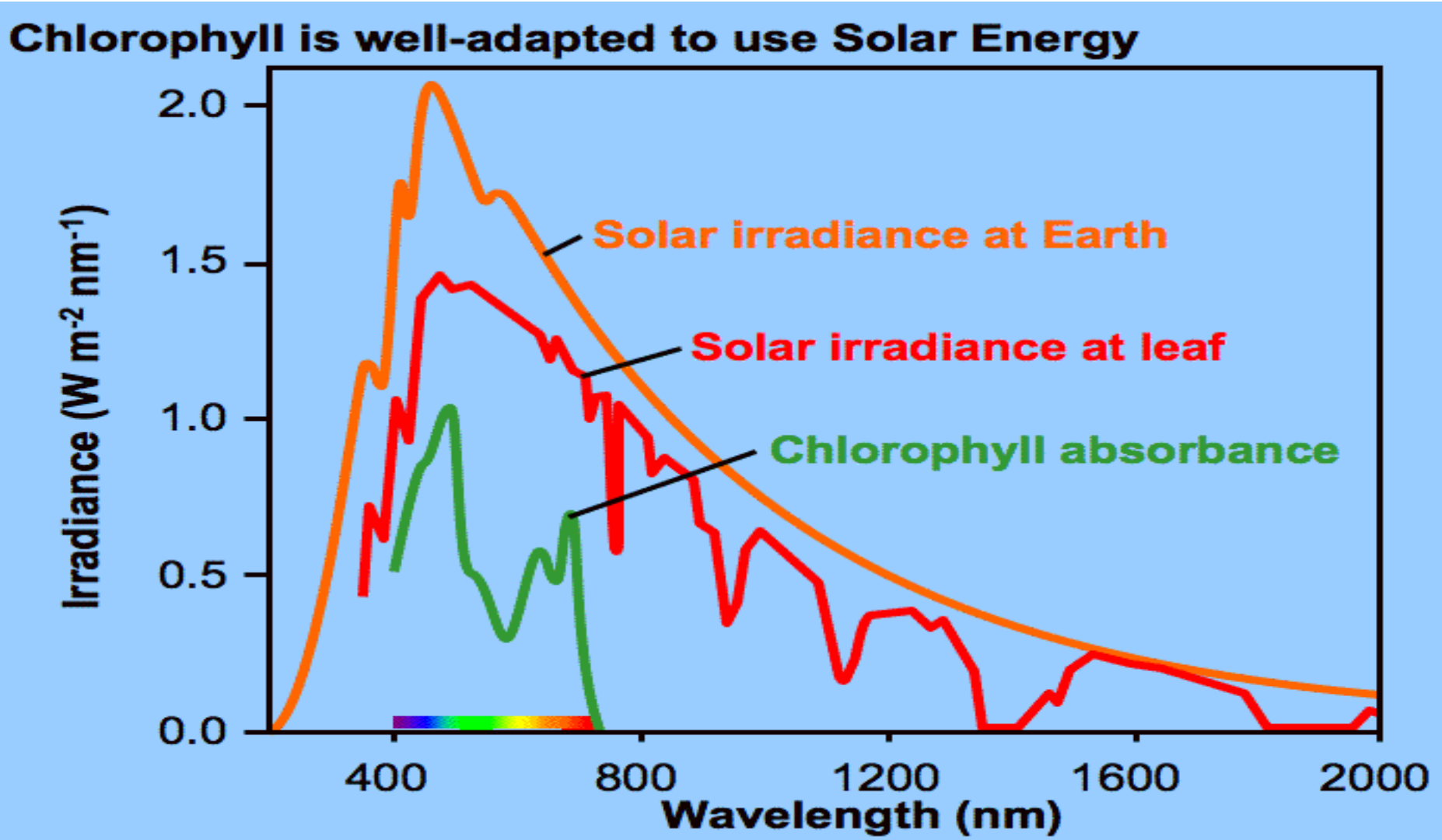
1) As temperature T of the body increases, intensity of the radiation from the body also increases

2) Higher the temperature, lower is the wavelength of the most intense part of the spectrum.



Black body Radiation


Spectral irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250°C Blackbody Spectrum
Radiation at Sea Level
O_3
O_2
H_2O
H_2O
H_2O
H_2O
CO_2
H_2O
Absorption Bands
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)


Chlorophyll is well-adapted to use Solar Energy
Irradiance (W m-2 nm-1)
2.0
1.5
1.0
0.5
0.0
Solar irradiance at Earth
Solar irradiance at leaf
Chlorophyll absorbance
400
800
1200
1600
2000
Wavelength (nm)

Visible Spectrum Wavelength:	400 nm (violet)	to	700 nm (red)
Corresponding band gaps:	3.1 eV	to	1.8 eV