Agronomy 406
World Climates
January 11, 2018

Greenhouse effect quiz.

Atmospheric structure and Earth's energy budget.

Review for today:

Online textbook: 2.1.1 The heat balance at the top of the atmosphere.

"Bad Greenhouse".

For Tuesday:

Online textbook: 2.1.4 The heat balance at the top of the atmosphere: geographical distribution

Reminder: Submit project title and description by start of class on Tuesday.

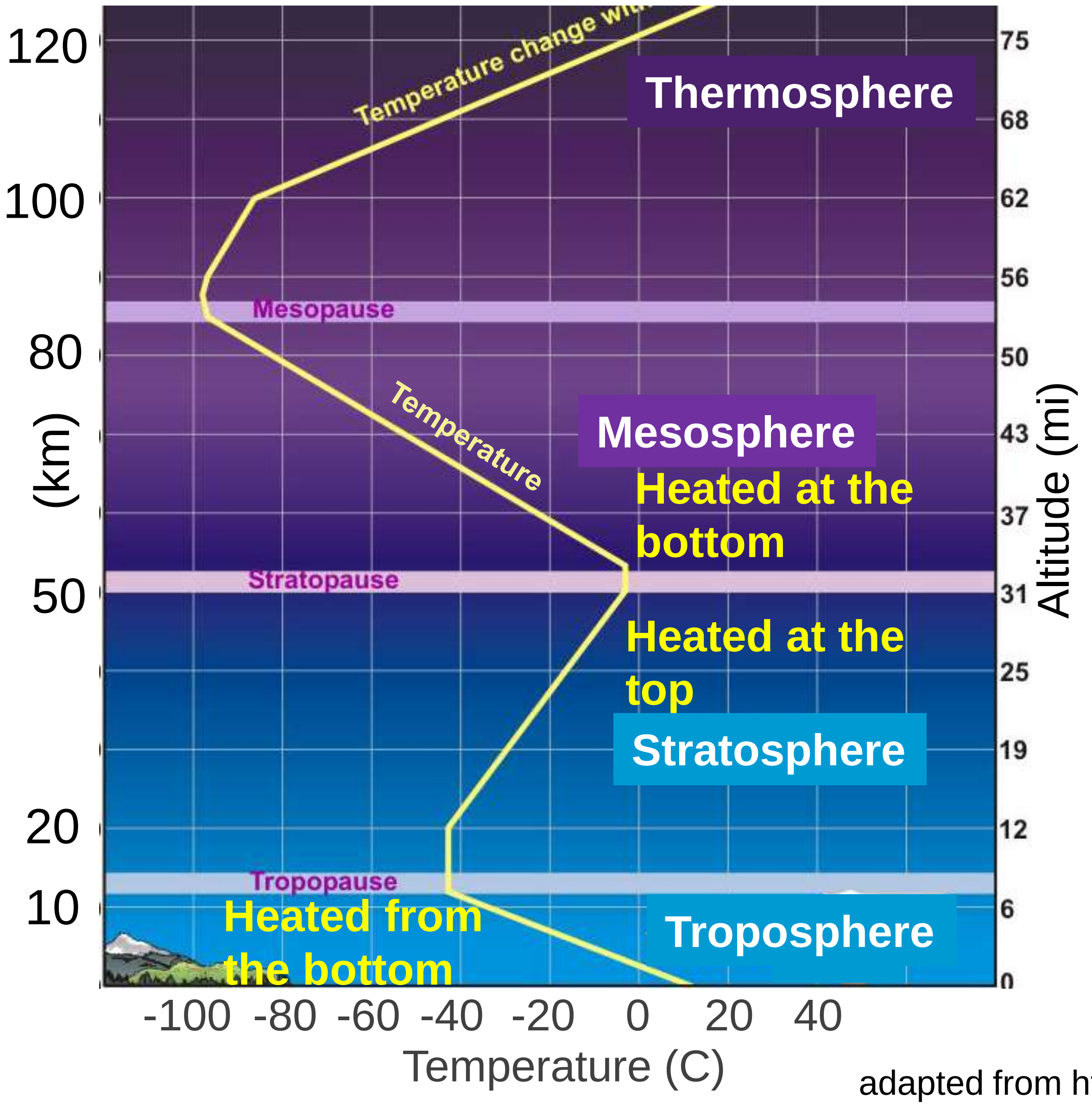
What is air?

Composition of dry air	
Gas	**Percentage**
Nitrogen	78.080
Oxygen	20.944
Argon	0.934
Carbon dioxide	0.041
Neon	0.002
All others	0.001

"All others" includes some gases with important effects despite very small concentrations, such as methane, ozone, and chlorofluorocarbons (CFCs).

Source: IUPAC Compendium of Chemical Terminology, 2nd ed. (1997). Adjusted for increase of carbon dioxide since publication.

Temperature profile of the atmosphere



Thermosphere is heated by high-energy radiation from the sun (such as X-rays).

The **mesosphere** is mostly heated from the bottom due to absorption of ultraviolet radiation by **ozone.**

The **stratosphere** is mostly heated from the top due to absorption of ultraviolet radiation by **ozone**.

The **troposphere** is heated mostly by energy from Earth's surface.

adapted from http://oceanservice.noaa.gov/education/yos/resource/JetStream/atmos/layers.htm

Earth's energy budget

For Earth to maintain a constant temperature, energy gains must equal energy losses – the budget must be **balanced.**

If more energy is gained than lost, Earth will warm.

If more energy is lost than gained, Earth will cool.

This applies only when averaged over the whole Earth.

We will look at energy gains, energy losses, and the balance between the two.

Energy gain from the sun: Short-wave radiation

Sun is the ultimate energy source for the atmosphere, land surface and oceans.

Global amount of shortwave (solar) radiation received at Earth's orbit is nearly constant:

- Small variations due to sunspot cycle (±0.1%)
- Larger variations (±3%) during the year due to eccentricity of Earth's orbit

Average value throughout the year is the **solar constant,** about 1361 watts per square meter.

- Online textbook has a slightly older value, 1368 W m^{-2}.

Energy loss to space: Long-wave radiation

Everything emits radiation according to the Stefan-Boltzmann law:

$$A\uparrow = \varepsilon\, \sigma\, T^4$$

$A\uparrow$ = emitted power **per unit area** (watts / square meter). Power is energy per unit time.

ε = emissivity. Ranges 0 to 1, with ε usually close to 1 for natural surfaces.

σ = Stefan-Boltzmann constant, 5.67 x 10^{-8} W m^{-2} K^{-4}.
(Easy to remember: why?)

T = temperature (in **kelvins** – relative to absolute zero)

Emission of radiation

Emitted power **per unit area** (watts per square meter) is

$$A\uparrow = \varepsilon \, \sigma \, T^4$$

Then **total** radiation emitted by an object is

$$R\uparrow = a \, \varepsilon \, \sigma \, T^4$$

where **a** is the surface area of the object.

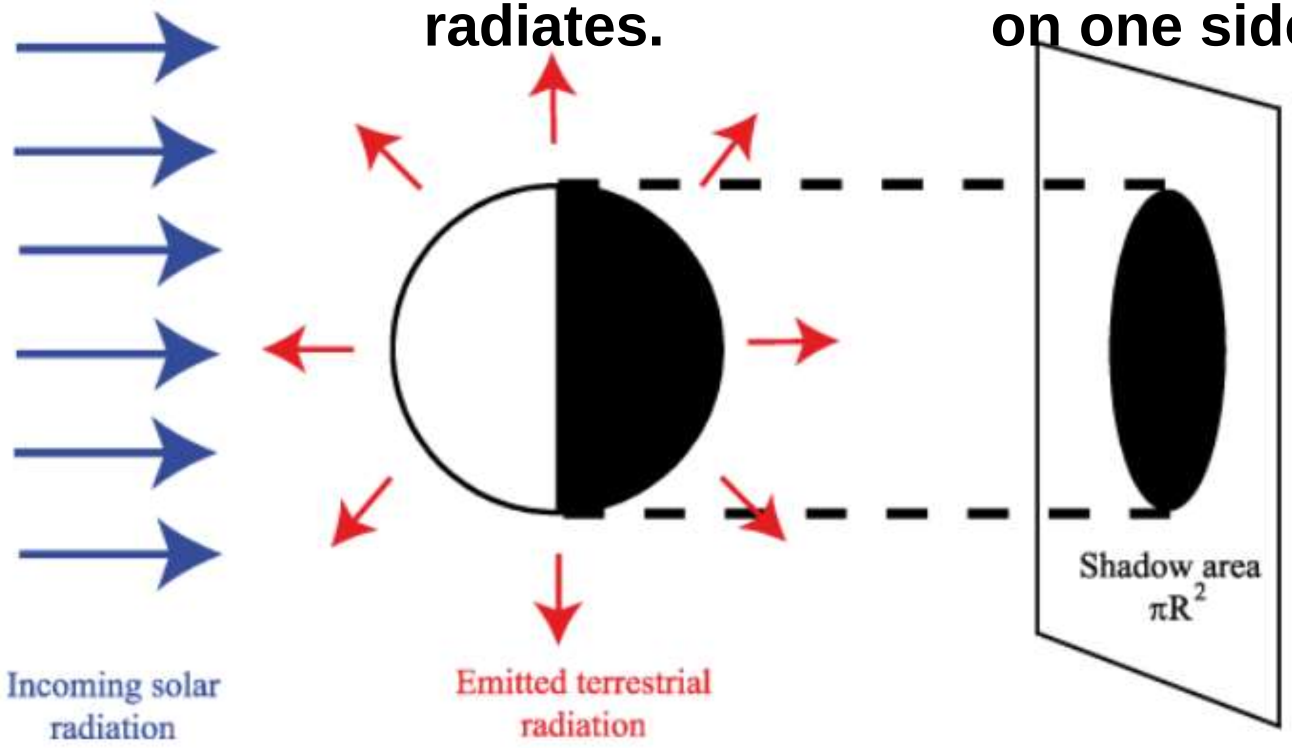
What is the total radiation (in watts) emitted by a typical adult human?

Work in your teams to estimate an answer. State any assumptions you use. Remember $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} and T is absolute temperature (kelvins).

Absorption and emission of radiation

Earth **radiates** as a sphere: The entire surface radiates.

Earth **intercepts sunlight** as a disc (circle): Lit only on one side.



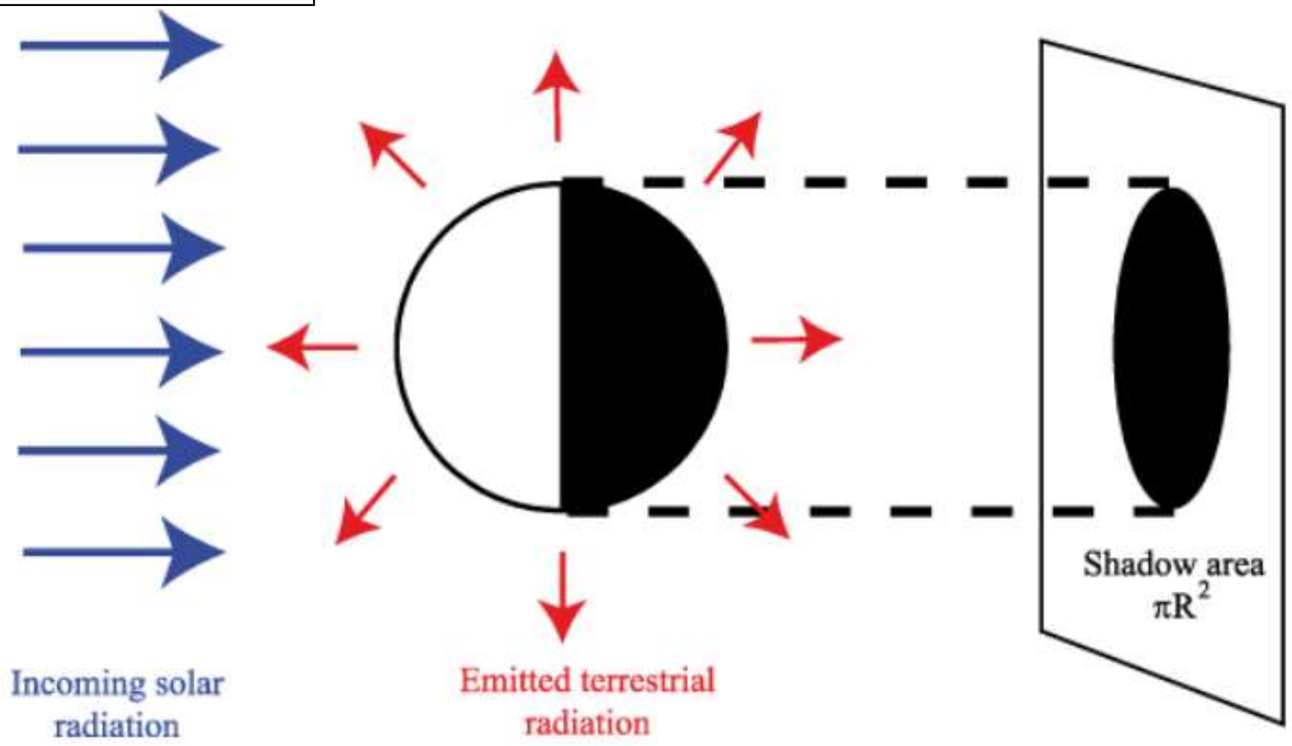
$$E_{out} = E_{in}$$

Absorption and emission of radiation

notice ratio of surface area of a disc to that of a sphere is 1/4

Area of sphere is $4\pi R^2$

Area of disc is πR^2



$$E_{out} = E_{in}$$

Energy balance

$$\boxed{E_{out} = E_{in}}$$

E_{out} = total energy emitted

= (surface area of sphere) x (energy emitted per unit area)

= $(4\pi R^2)$ x (σT^4)

E_{in} = total energy absorbed

= (area of disc) x (solar constant) x (fraction absorbed)

= (πR^2) x S_o x $(1-\alpha_p)$

where α_p is the fraction **reflected**, called the **planetary albedo** (about 0.3)

Energy balance

Then

$$\boxed{E_{out} \quad = \quad E_{in}}$$

becomes

$$(4\pi R^2) \times (\sigma T_e^4) = (\pi R^2) \times S_0 \times (1-\alpha_p)$$

We know π, R, σ**,** S_0 and α_p.

Then we can solve for T_e.

Solving the global energy balance

$$E_{out} = E_{in}$$

$$4\pi R^2 \sigma T_e^4 = S_0 \pi R^2 (1 - \alpha_p)$$

S_o = solar "constant" (1361 W m^{-2})

R = radius of Earth (6378 km)

α_p = planetary albedo (about 0.30)

σ = Stefan-Boltzmann constant = 5.67×10^{-8} W m^{-2} K^{-4}

In your teams:

1. **Solve for T, the mean Earth temperature.**
2. **Convert your answer to Fahrenheit.**
3. **Is this a reasonable value for the average surface temperature of Earth?**

Solving the global energy balance

Start with

$$4\pi R^2\sigma T_e^4 = S_0\pi R^2(1- \alpha_p)$$

Cancel πR^2 from both sides:

$$4\sigma T_e^4 = S_0 (1- \alpha_p)$$

We want T_e on one side of the equation and everything else on the other side. So divide both sides by 4σ:

$$T_e^4 = S_0 (1- \alpha_p) / 4\sigma$$

Take the 1/4 power of both sides to get

$$T_e = [S_0 (1- \alpha_p) / 4\sigma]^{1/4}$$

Example

We rearranged the equation to get

$$T_e = [S_0 \, (1- \alpha_p) \, / \, 4\sigma]^{1/4}$$

Then plug in: $S_0 = 1361 \text{ W m}^{-2}$

$\alpha_p = 0.30$

$\sigma = 5.67\times10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

We get

$T_e = [1361 \text{ W m}^{-2} \, (1 - 0.3) \, / \, (4\times5.67\times10^{-8} \text{ W m}^{-2} \text{ K}^{-4})]^{1/4}$

Cancel W m^{-2} in the numerator and denominator and do the arithmetic to get $T = [4.20\times10^{9} \text{ K}^{4}]^{1/4}$

$T =$ **254.58 K**

Example

$T =$ **254.58 K**

Convert to Fahrenheit.

Possibly easiest if we convert to Celsius first.

$0^oC = 273.15$ K

Then $T_C = 254.58 - 273.15 =$ **$-18.57\ ^oC$**

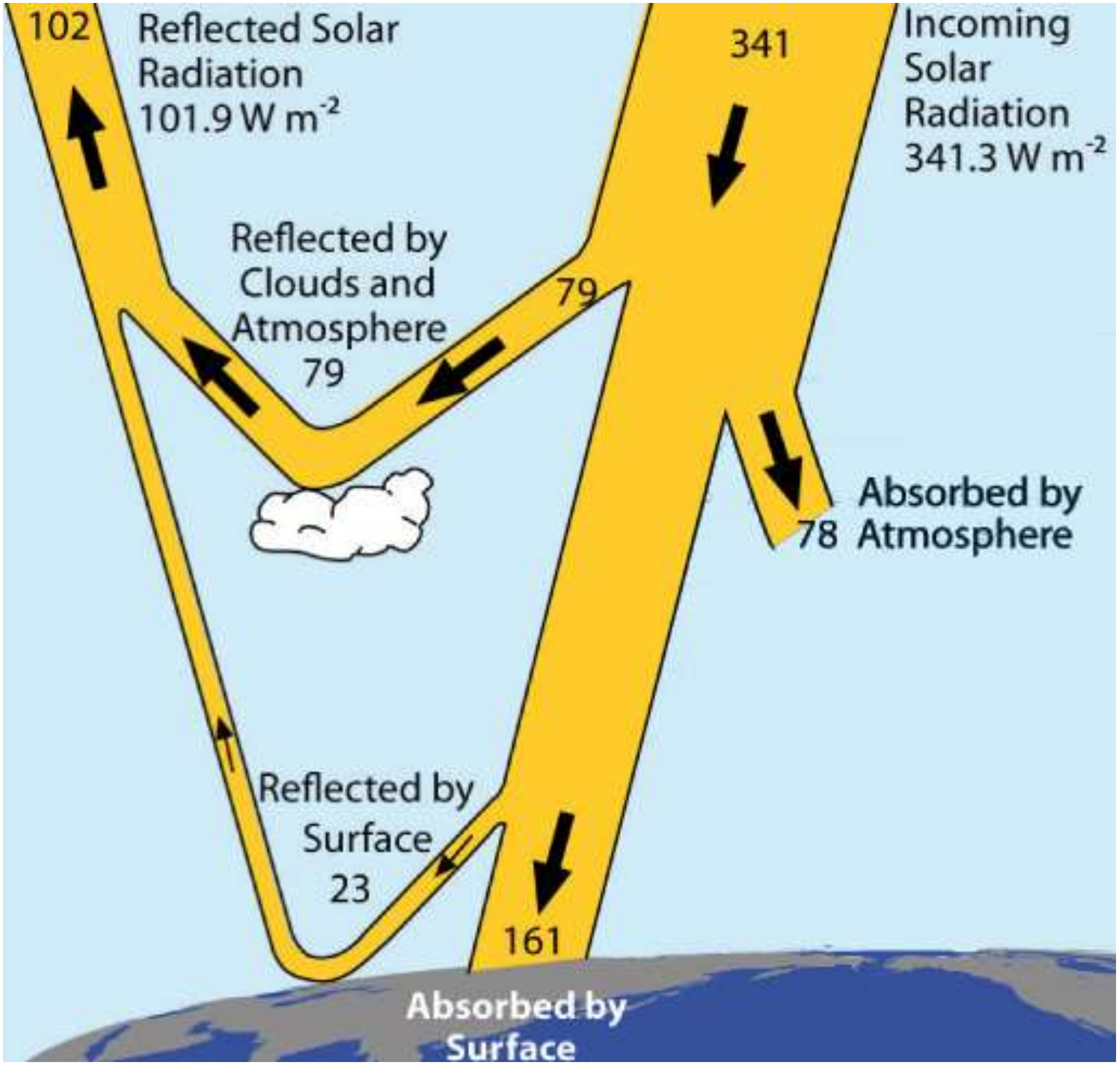
Convert from Celsius to Fahrenheit:

$T_F = 32 + (9/5 \times T_C)$

$= 32 + (9/5 \times -18.57) =$ **$-1.4\ ^oF$**

Too cold! Actual average temperature of Earth's surface is much warmer. The difference is due to the **greenhouse effect.**

Short-wave radiation budget



planetary albedo =

reflected / incoming

= (102 W m^{-2})/(341 W m^{-2})

= 0.30

gain to atmosphere

= 78 W m^{-2}

gain to surface

= 161 W m^{-2}

total gain to system

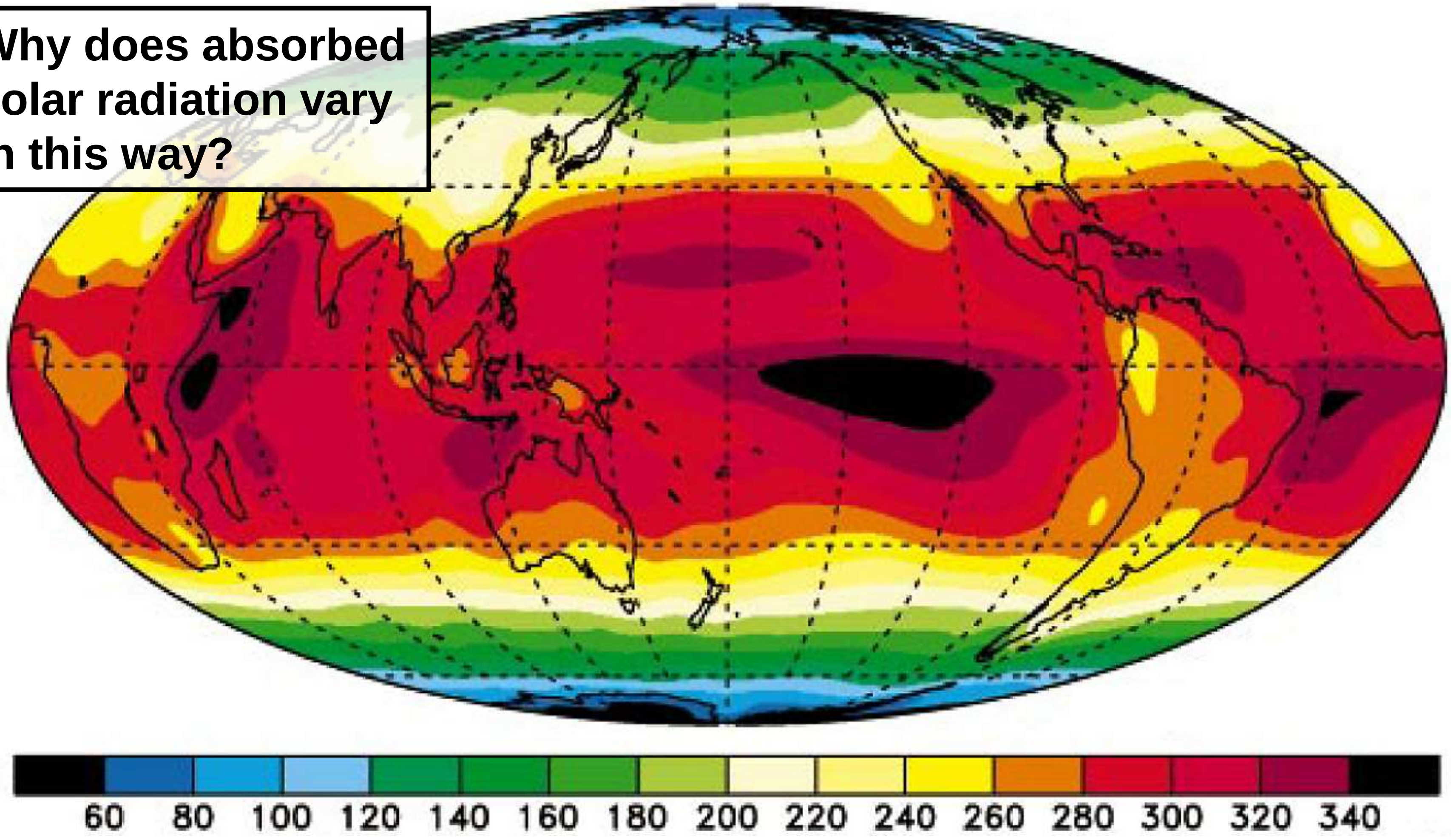
= (incoming - reflected)

= (341 - 102) W m^{-2}

= 239 W m^{-2}

Solar radiation absorbed by Earth (measured at top of the atmosphere)

Why does absorbed solar radiation vary in this way?



annual mean, W m^{-2}

Trenberth and Stepaniak (2003)