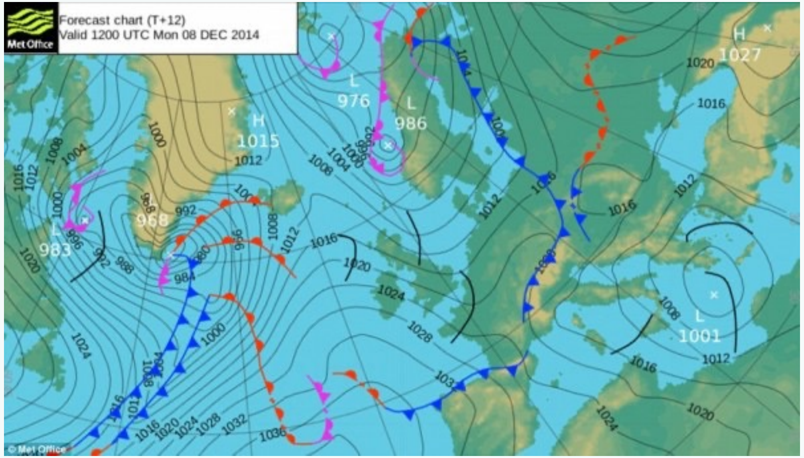
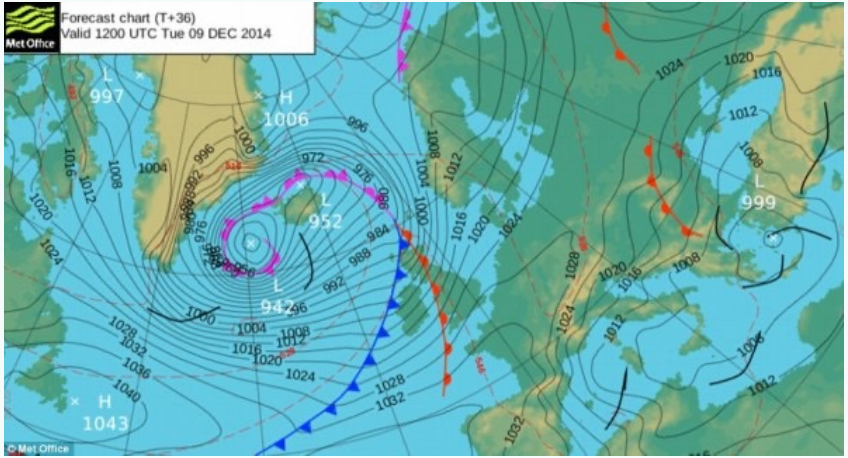
DEPARTMENT OF GEOGRAPHY

Climate

GEOG0005

Name that Weather System





The 2 synoptic maps above are 24 hours apart. What is the weather system in the panel on the right off the southeast coast of Greenland?

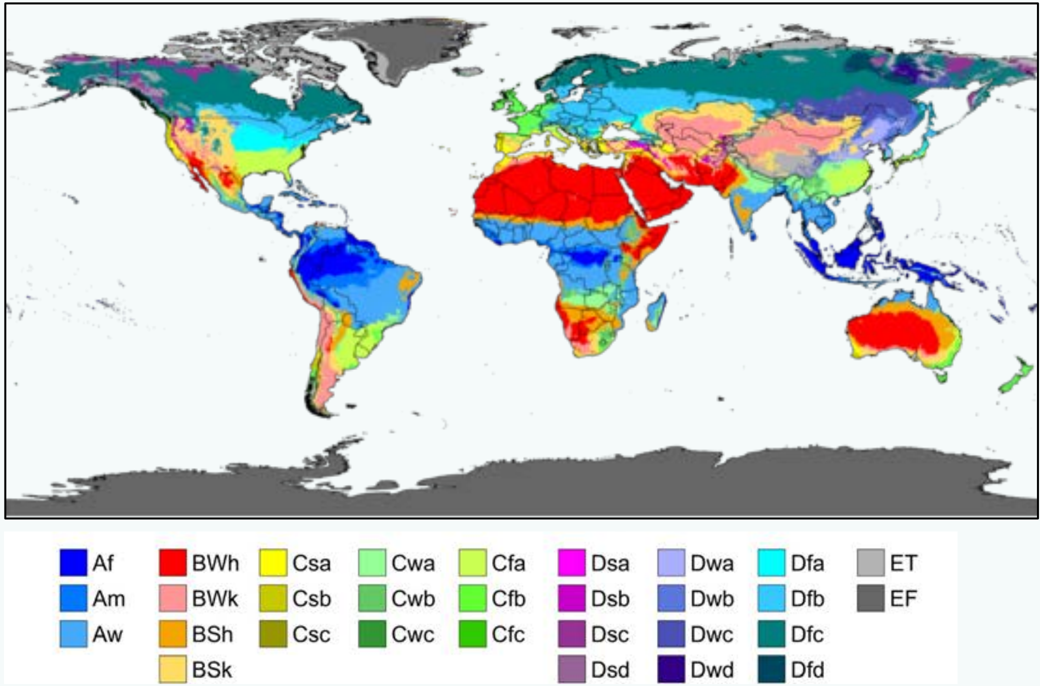
A. An occluded front
B. An anticyclone
C. A cyclone
D. Blocking

What is the term for the transition from the system on the left to that on the right?

What is climate?

- **Average** or typical conditions of the atmosphere
- The state of climate components or variables (temperature, precipitation)
- Classify according to land cover, seasonal precipitation, temperature (Köppen)
- Averages out weather, but not seasons
- Climate measurements span modern to past climate (paleoclimate)

Köppen climate classification map (1980-2016)



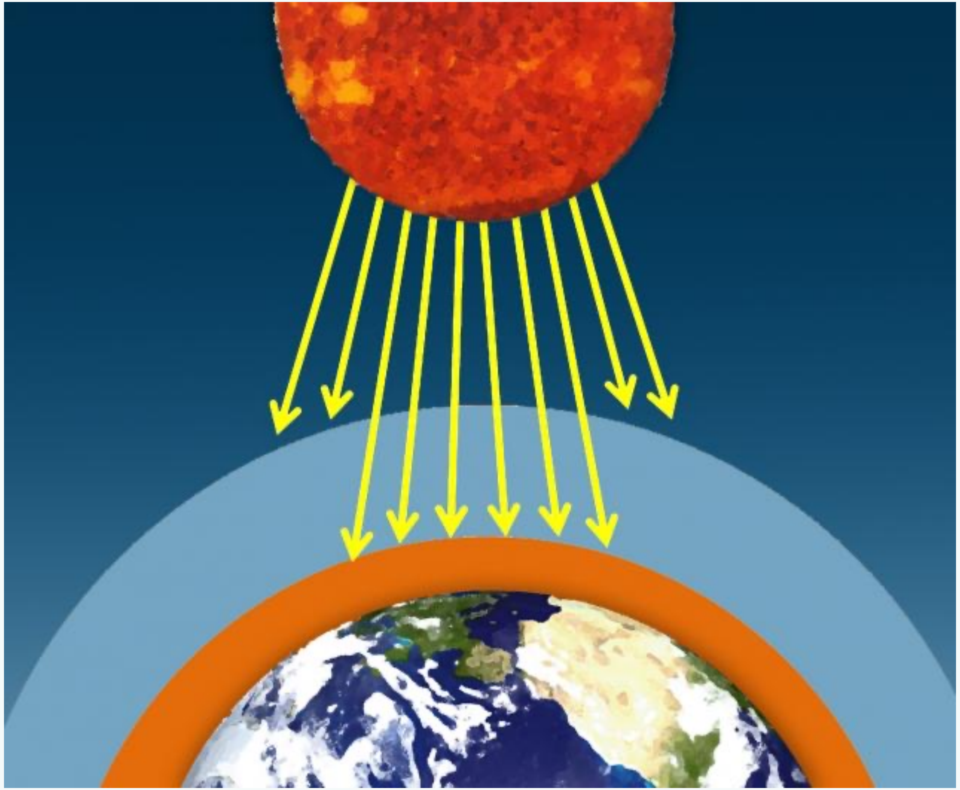
A = Tropical
B = Dry (arid/semi-arid)
C = Temperate
D = Continental
E = Polar

WHAT CONTROLS CLIMATE?

Global Energy Budget

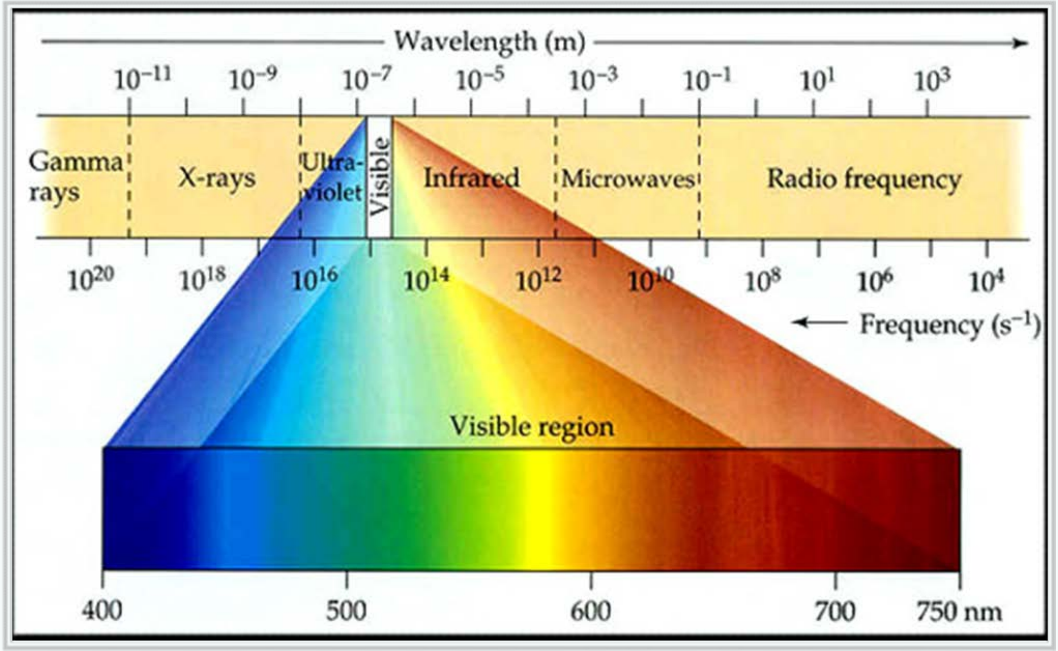
Energy Transfer

- Radiation
- Conduction
- Convection



Radiation

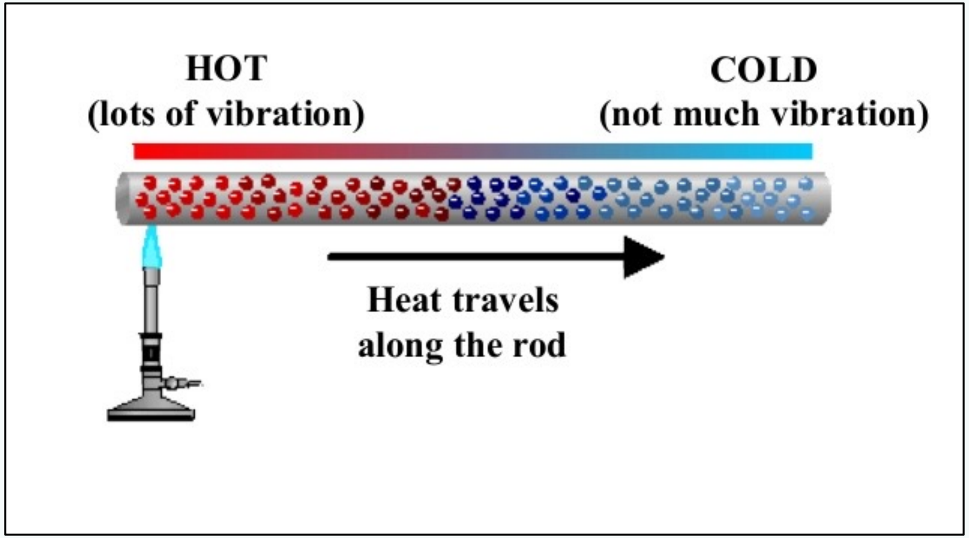
- Transfer of energy as waves or particles through air (emission/transmission)
- Called electromagnetic radiation
- Electromagnetic spectrum: range of frequencies of electromagnetic radiation and their wavelengths (or energies)
- Includes **longwave** (low energy) and **shortwave** (high energy) radiation



Energy is inversely proportional to wavelength

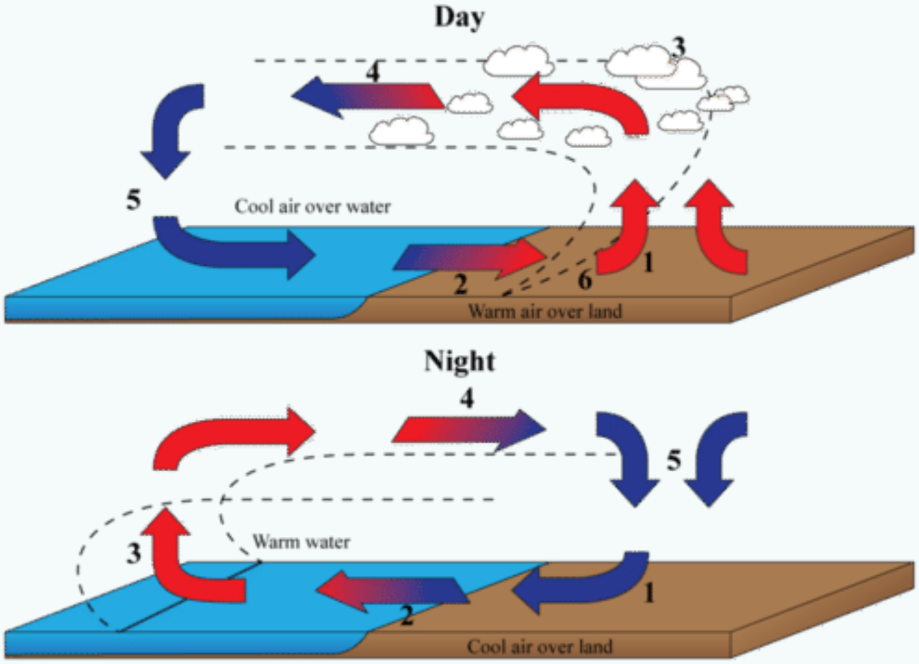
Conduction

- Heat (energy) transfers from one molecule to next as molecules vibrate
- Rate of transfer of heat depends on temperature difference (gradient)
- Example: heat moving along a metal bar
- Occurs in all fluid phases (gas, liquid, solid)

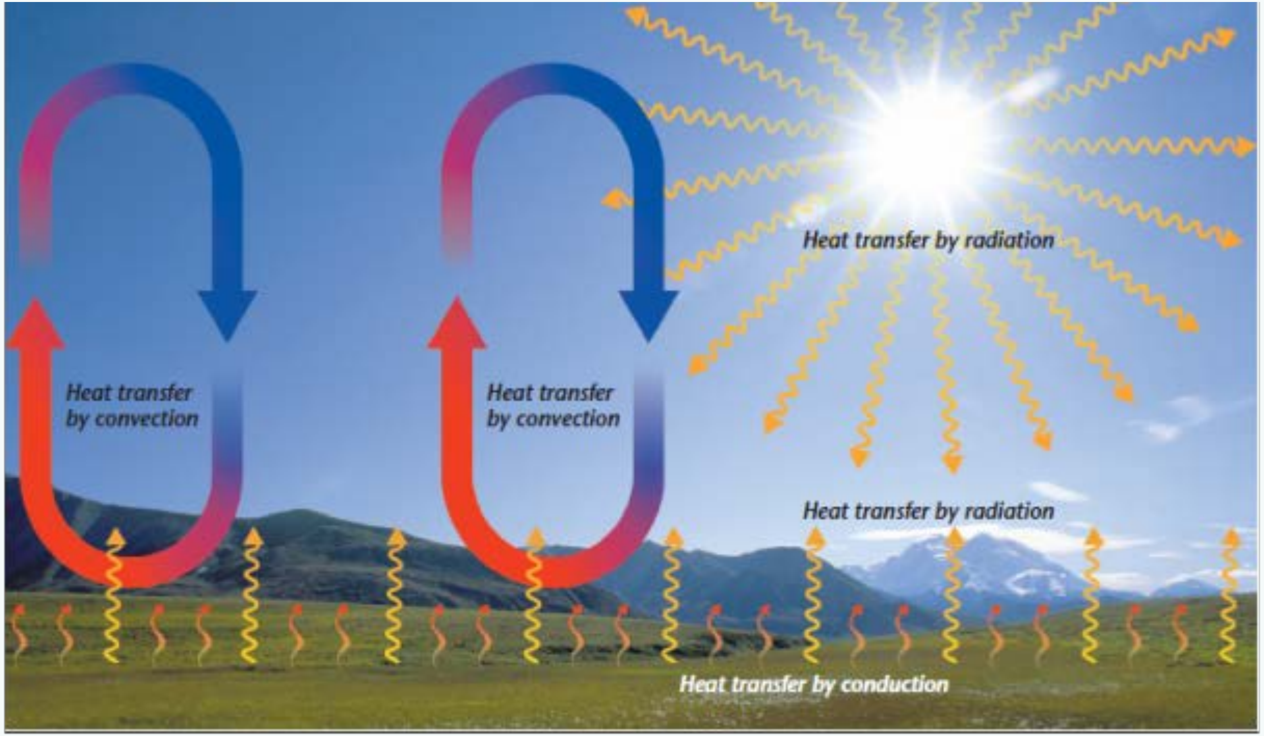


Convection

- Transfer of heat by movement of a fluid (mass transfer)
- Caused by buoyancy forces due to changes in density that arise from changes in temperature
- These present in the atmosphere as turbulence (fluid mixing) or an instability (uneven heating)
- Moist convection leads to thunderstorms



Heat Transfer Processes in the Atmosphere



Test Your Understanding

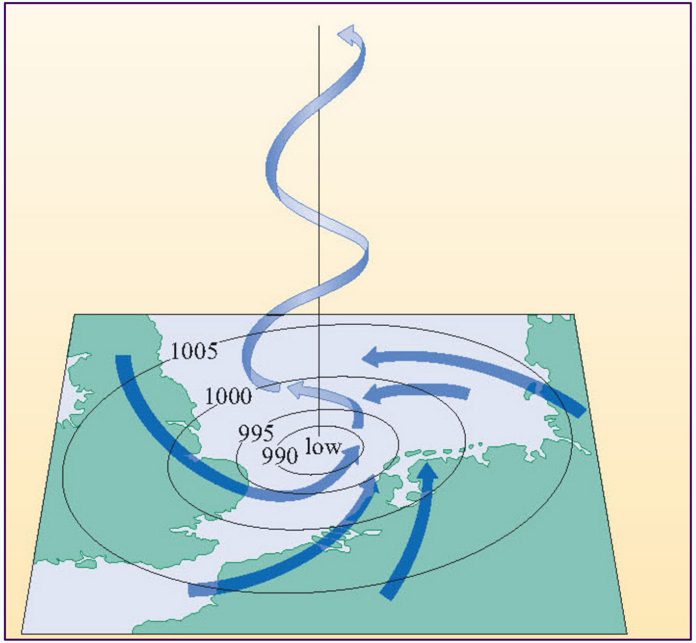
What kind of heat transfer is taking place above the low-pressure system of a cyclone?

A. Conduction

B. Convection

C. Radiation

D. None of these



Steady State

- Earth's climate system, unperturbed, is in a (quasi-) steady state:

Energy In = Energy Out

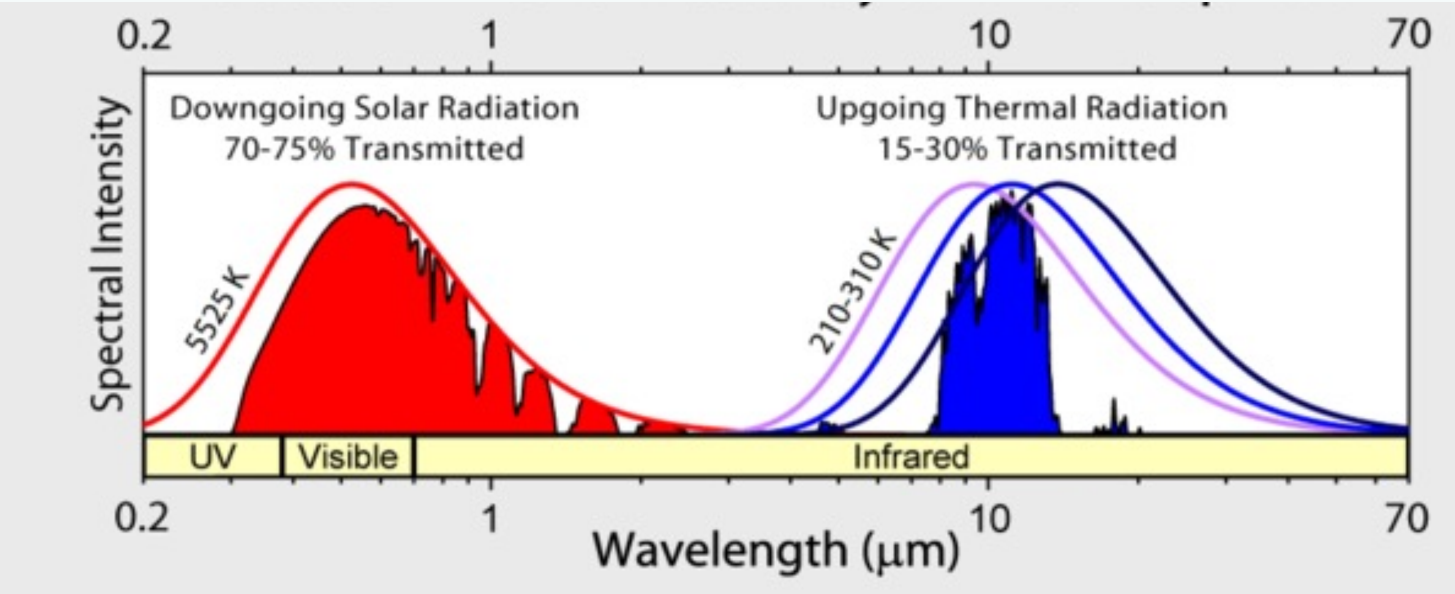
(Incoming radiation = Outgoing radiation)

- As space is a vacuum, the only form of energy transfer is electromagnetic radiation

Longwave and Shortwave

Radiation from the sun is in the shortwave (UV/visible)

Radiation from the Earth is in the longwave (infrared)



Emission from the sun and Earth hardly overlap

Blackbody Radiation

- Perfect blackbody absorbs all incoming radiation (none is reflected)
- Radiation emitted by a blackbody depends only on its temperature
- Planck's law of blackbody radiation defines this relationship:

Planck's Law:

$$\boxed{B(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}}$$

B: radiance
h, c, k: constants
ν: frequency of light
T: absolute temperature

- Radiance: Power emitted by the blackbody [in $W/m^2/sr$]
- Tells us how much radiation emitted at a certain wavelength for a body of a certain temperature
- Blackbody is isotropic (radiation emitted at equal intensity in all directions)

Stefan-Boltzmann Law

- Relates power radiated from a blackbody to its temperature
- Total energy radiated per unit surface area of a blackbody is proportional to T^4
- This relationship integrated in all directions over a hemisphere and over all frequencies:

$$I = \sigma T^4$$

where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} *is the Stefan-Boltzmann Constant*

- I is the blackbody irradiance (power per unit area in W/m^2)

Test Your Understanding

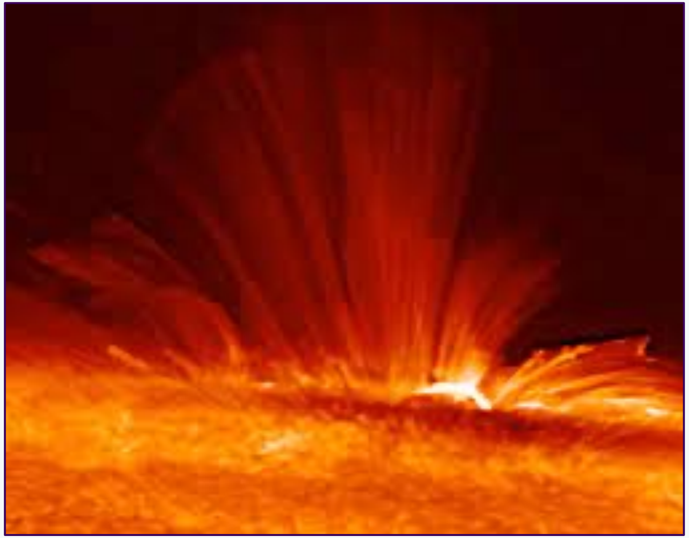
The Stefan-Boltzmann constant is 5.67×10^{-8} W m^{-2} K^{-4} and the temperature of the sun is 5778 K. What is the energy radiated from the surface of the sun?

A. 5778 W/m^2

B. 63000 kW

C. 63000 kW/m^2

D. 0.0032 W/m^2



Radiation Modifiers

- **Albedo**, α, is the ratio of reflected radiation to incident radiation (incoming light striking a surface):

$$0 < \alpha < 1$$

- **Transmittance**, γ, is the ratio of transmitted radiation (radiation that passes through a fluid) to incident radiation:

$$0 < \gamma < 1$$

- **Emissivity**, ε, is the amount of radiation emitted or absorbed by a body compared with that of a blackbody (0 for shiny object; 1 for blackbody):

$$0 < \varepsilon < 1$$

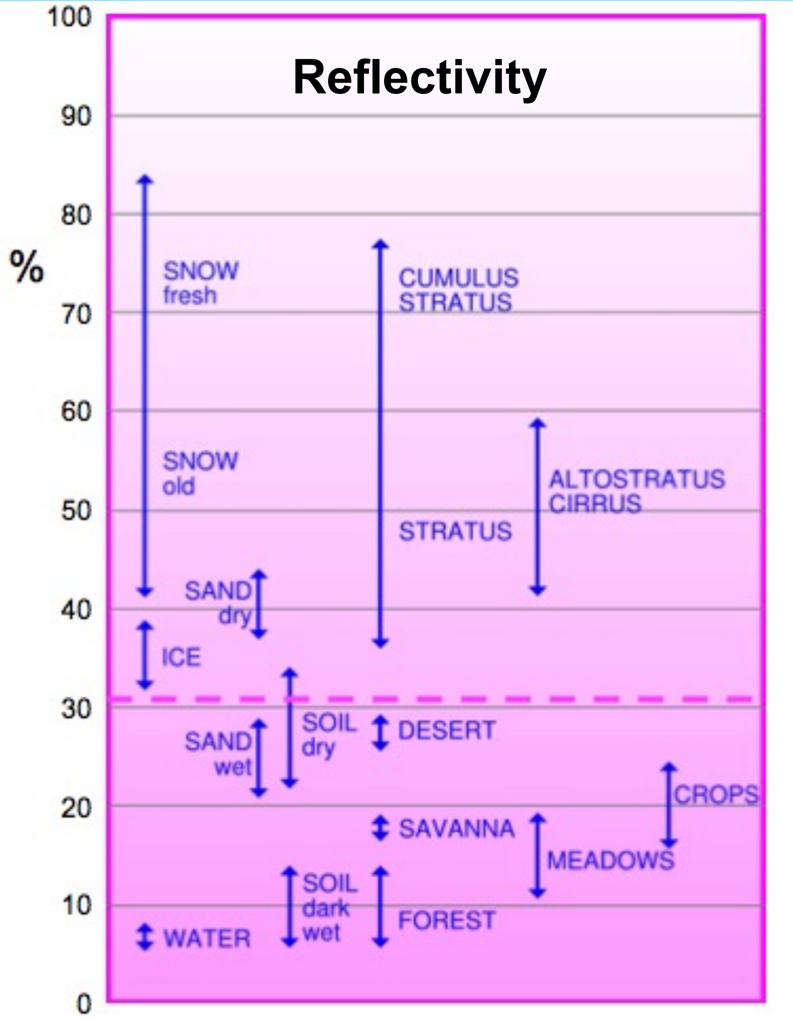
A grey body has $\varepsilon < 1$

Earth's Albedo

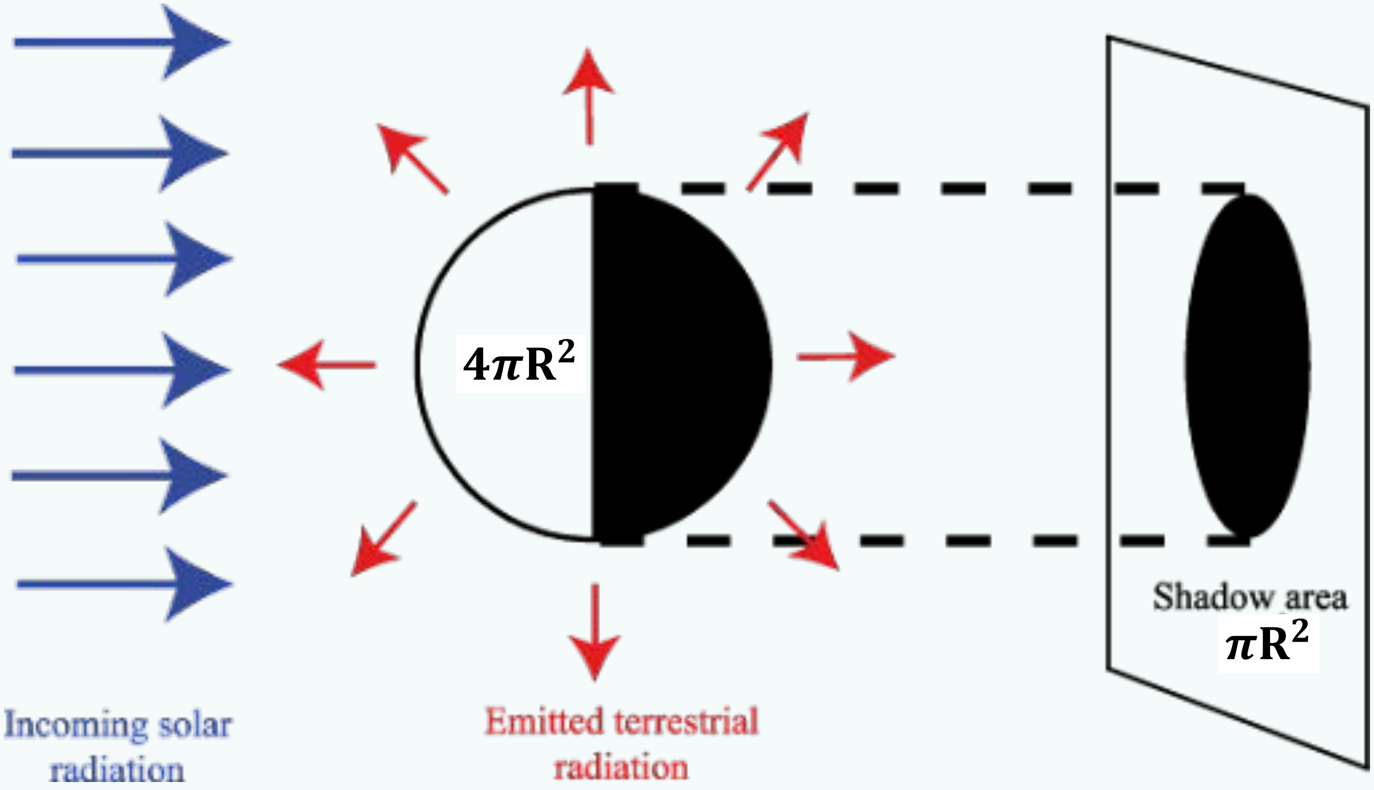
- Earth is not a perfect blackbody
- Clouds, ice, reflective land surfaces like deserts increase α and reduce ε
- Albedo (α) varies as a function of properties of surface

Albedo Properties of Earth's surface

- The albedo of the ocean depends on the angle of the solar radiation striking the surface (sun glint)
- The albedo of bare sea ice depends on the density of air bubbles.
- Earth's global average **α = 0.3**

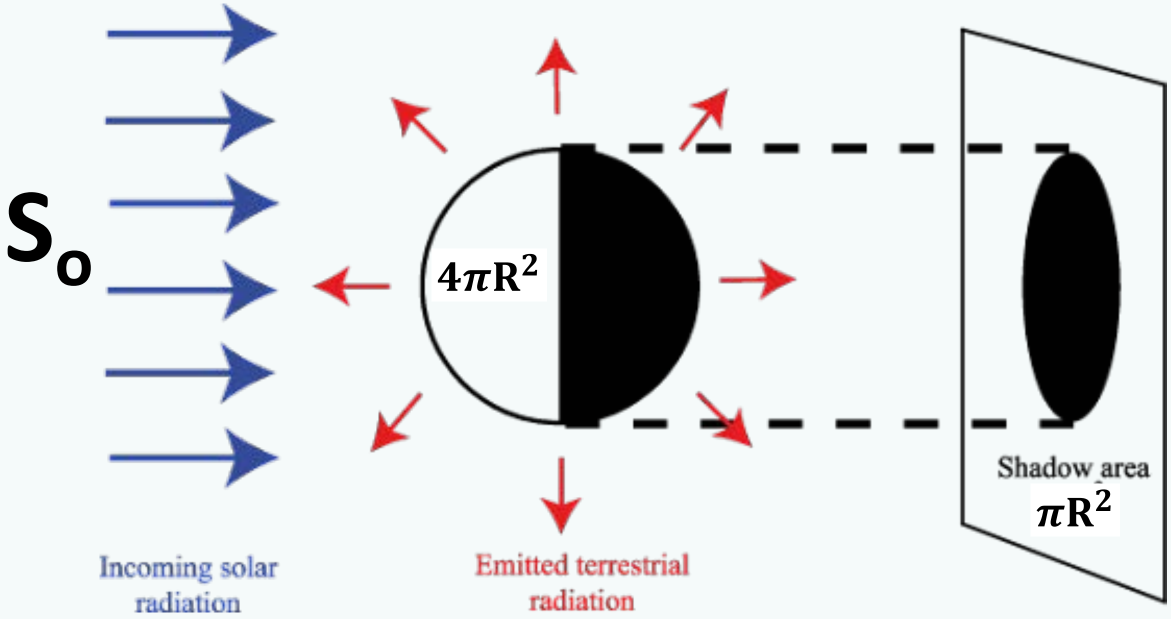


Global Mean Energy Model (**incoming radiation**)



Global Mean Energy Model (**incoming radiation**)

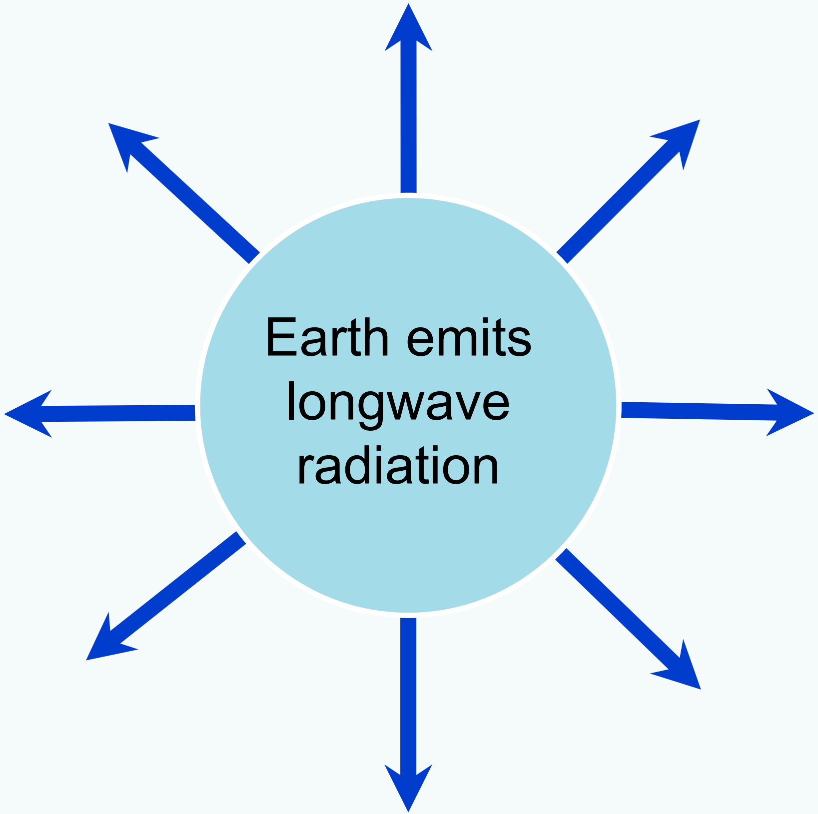
- Radiation energy received from the Sun at the top of the atmosphere per unit area (solar constant): $\mathbf{S_o = 1366\ W/m^2}$



Global Mean Energy Model (**incoming radiation**)

- Area of Earth = $4\pi R^2$
- Area of the Earth the sun intercepts = πR^2
- Fraction of S_o received by Earth = $(\pi R^2)/(4\pi R^2)$
  $= S_o/4$
- 30% will be reflected due to Earth's albedo ($\varepsilon = 1 - \alpha = 0.7$)
- Energy of sun incident on Earth = $\varepsilon S_o/4$

Global Mean Energy Model (**outgoing radiation**)



Energy of a blackbody is proportional to its temperature:

$$E_{out} = \sigma T_{surf}^4$$

($\sigma = 5.67\text{x}10^{-8}$ W m^{-2} K^{-4})

Global Mean Model
(incoming radiation = outgoing radiation)

Steady state: Energy in = Energy out

$$\varepsilon S_o/4 = \sigma T_{surf}^4$$

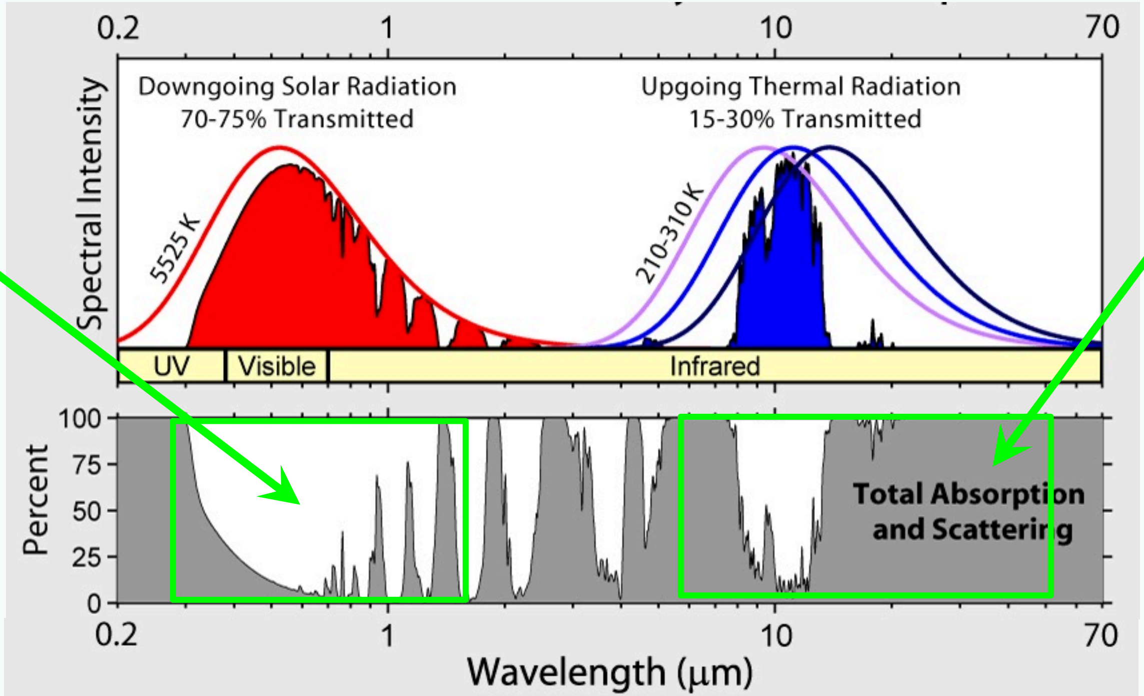
$$T_{surf} = \frac{\sqrt[4]{S_o(1-\alpha)}}{4\sigma}$$

T_{surf} = 255 K = -18°C

Too cold to be habitable. Actual temperature is +15°C.

Longwave and Shortwave Radiation

Majority of shortwave penetrates atmosphere

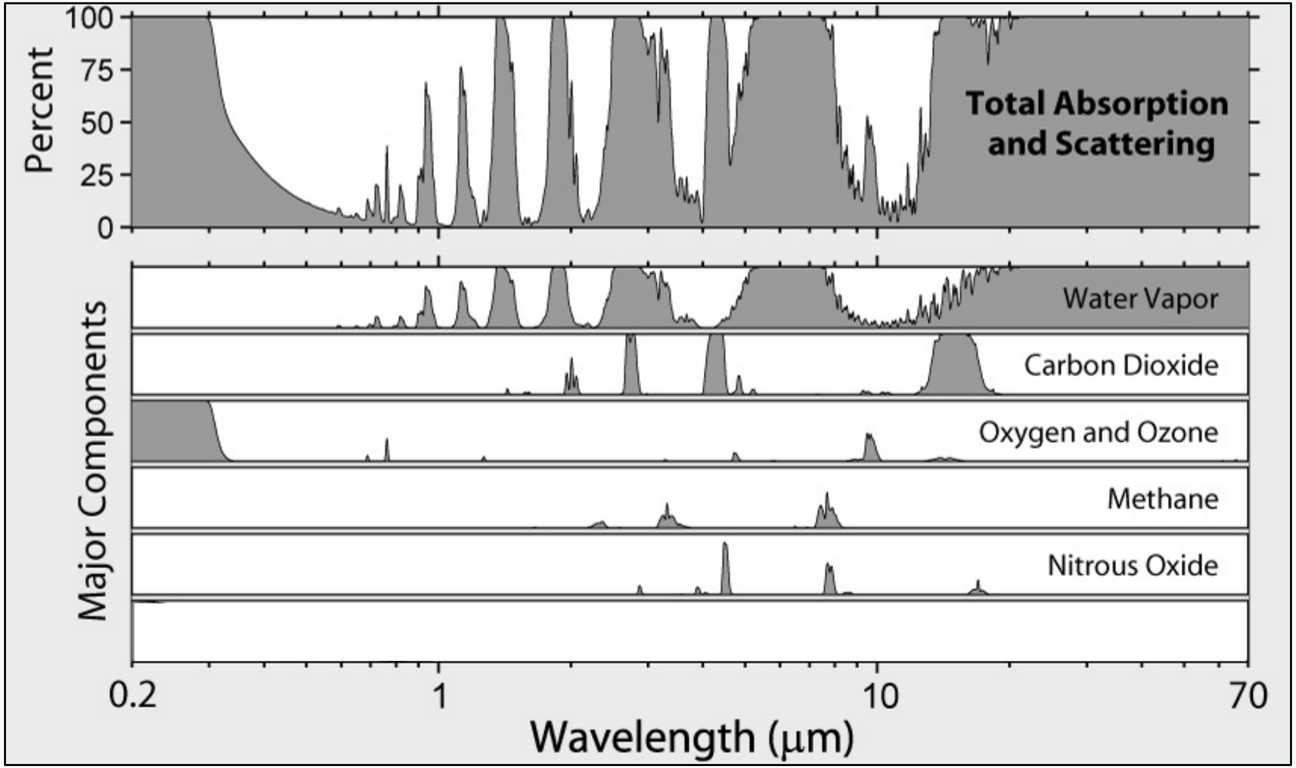


Very little longwave escapes

Absorption of Radiation by Greenhouse Gases

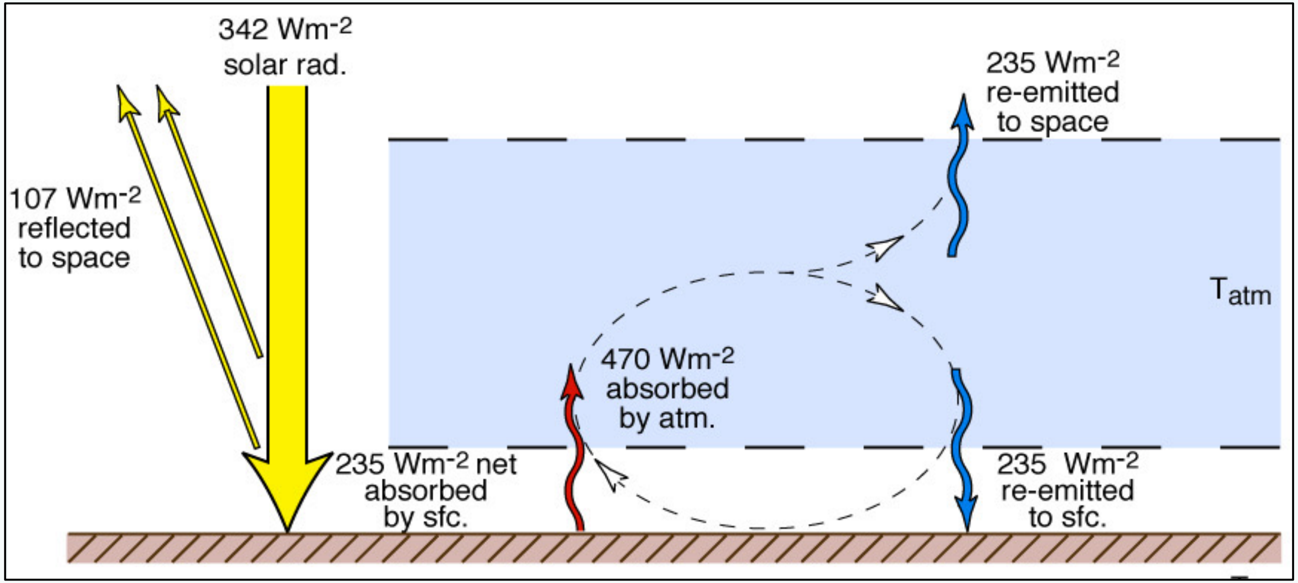
Majority of radiation emitted from surface is absorbed by atmosphere

Dominant GHGs are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)



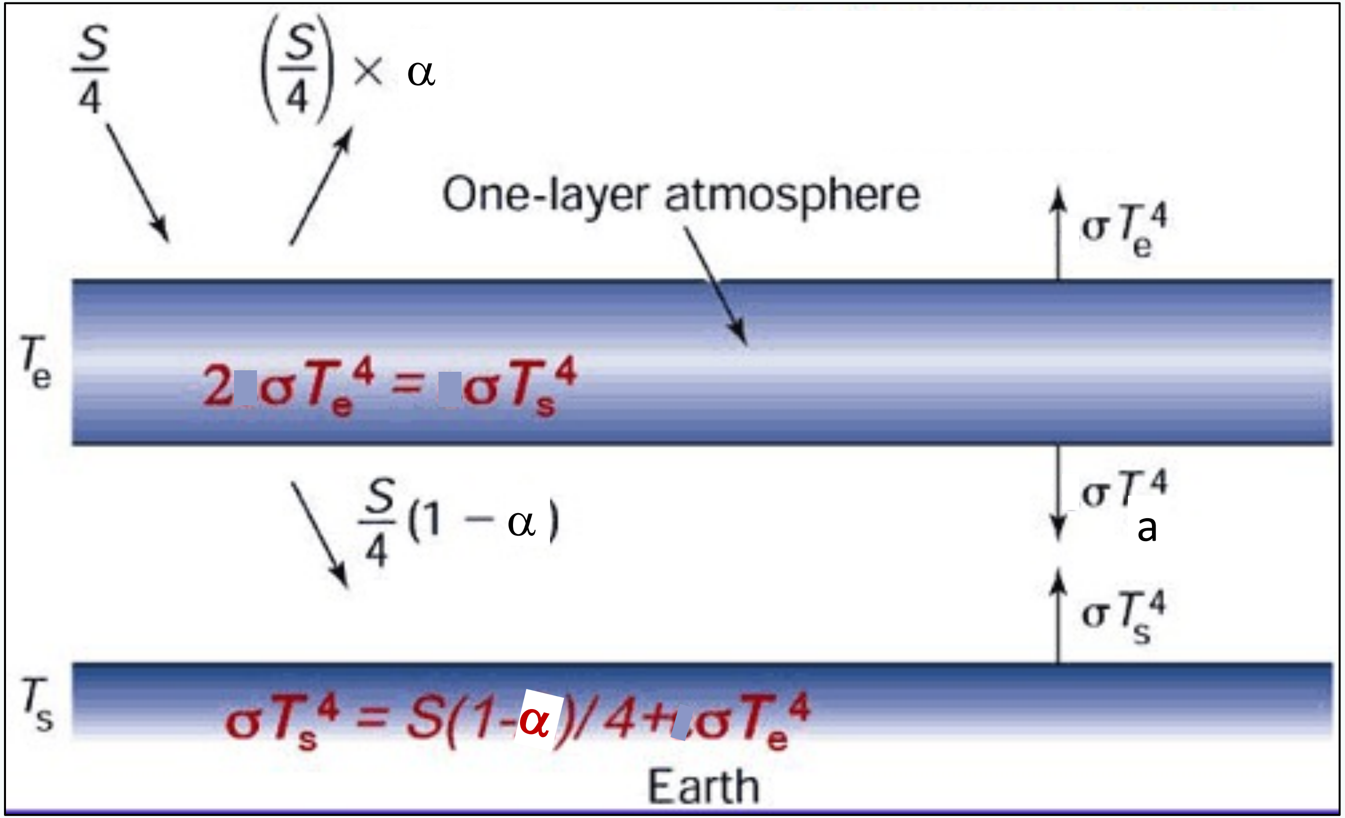
Add a GHG Layer to the Simple Model

‘Gray’ atmosphere is transparent in the shortwave and includes a layer of infrared absorbing gases that intercept outgoing longwave radiation



sfc. = surface

1 layer energy balance model



T_e is T_a in the example on the board and the slides that follow

Greenhouse gas atmosphere temperature

- Surface energy balance:

$$\varepsilon S_o/4 + \sigma T_a{}^4 = \sigma T_{surf}^4$$

- Atmosphere energy balance:

$$\sigma T_{surf}{}^4 = 2\sigma T_a{}^4$$

$$T_{surf} = 2^{1/4} T_a$$

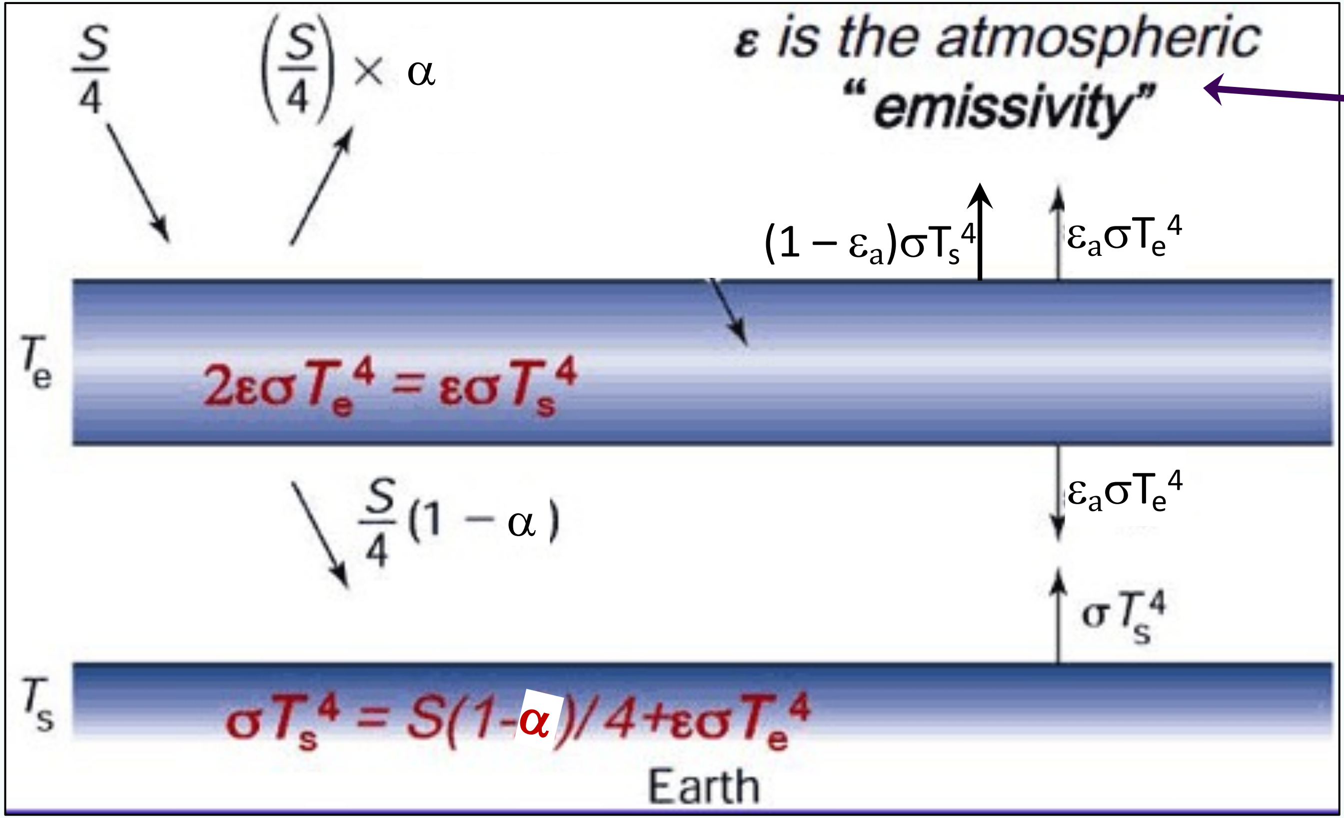
$$T_a = [\varepsilon S_o/4\ /\sigma]^{1/4}$$

T_a= 255 K = -18^{o}C

T_{surf} = 303 K = 30^{o}C

Too hot!

1 layer energy balance model



ε_a ~0.77

T_e is T_a in the example on the board and the slides that follow

Greenhouse gas atmosphere temperature

- Surface energy balance:

$$\varepsilon_{\mathrm{sun}} S_{\mathrm{o}}/4 + \varepsilon_{\mathrm{a}} \sigma \mathrm{T_a}^4 = \sigma T_{\mathrm{surf}}^4$$

- Atmosphere energy balance:

$$\varepsilon_{\mathrm{a}} \sigma \mathrm{T_{surf}}^4 = 2\varepsilon_{\mathrm{a}} \sigma \mathrm{T_a}^4$$

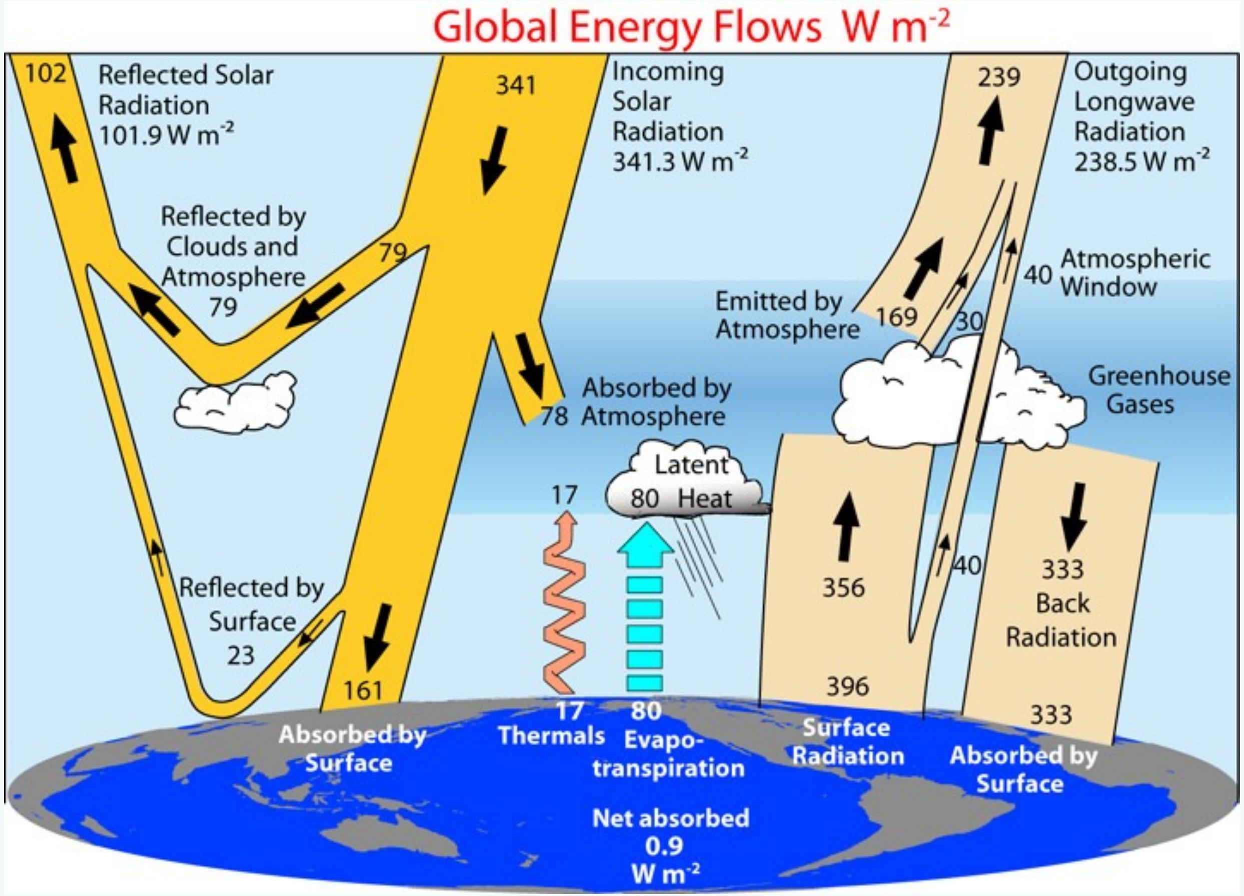
$$\mathrm{T_{surf}} = 2^{1/4}\mathrm{T_a}$$

$\mathrm{T_{surf}}$ = 288 K = 15$^{\mathrm{o}}$C

$\mathrm{T_a}$= 242 K = -31$^{\mathrm{o}}$C

Just right!

Putting it all together: Earth's Energy Balance



Test Your Knowledge

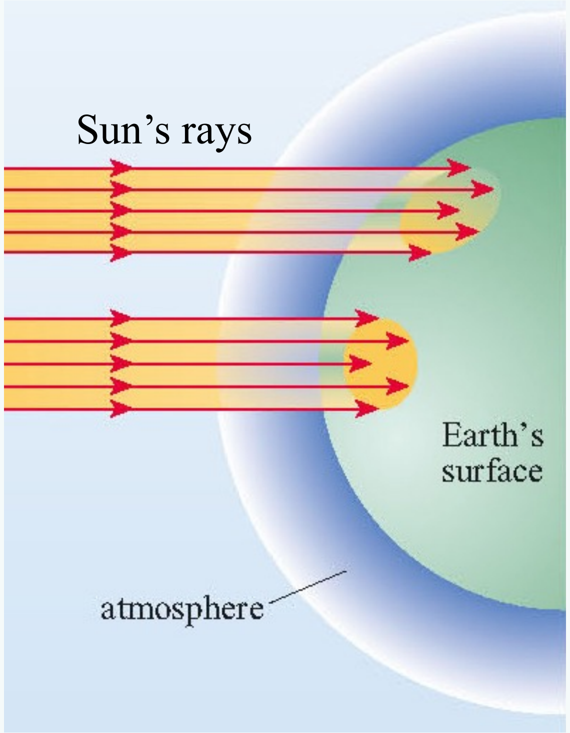
The solar constant for Mars is 586.2 W/m^2 and the albedo is 0.25. What is the blackbody temperature of Mars?

A. -48 degrees C
B. -63 degrees C
C. 19 degrees C
D. The same as Earth's blackbody temperature.

Why is the blackbody temperature of Mars less than that of Earth?

A. Mars is further from the sun than Earth.
B. Mars has a thinner atmosphere than Earth.
C. Mars has more atmospheric dust than Earth.
D. Mars has a lower atmospheric concentration of greenhouse gases than Earth.

Equator gets more sun radiation than the Poles

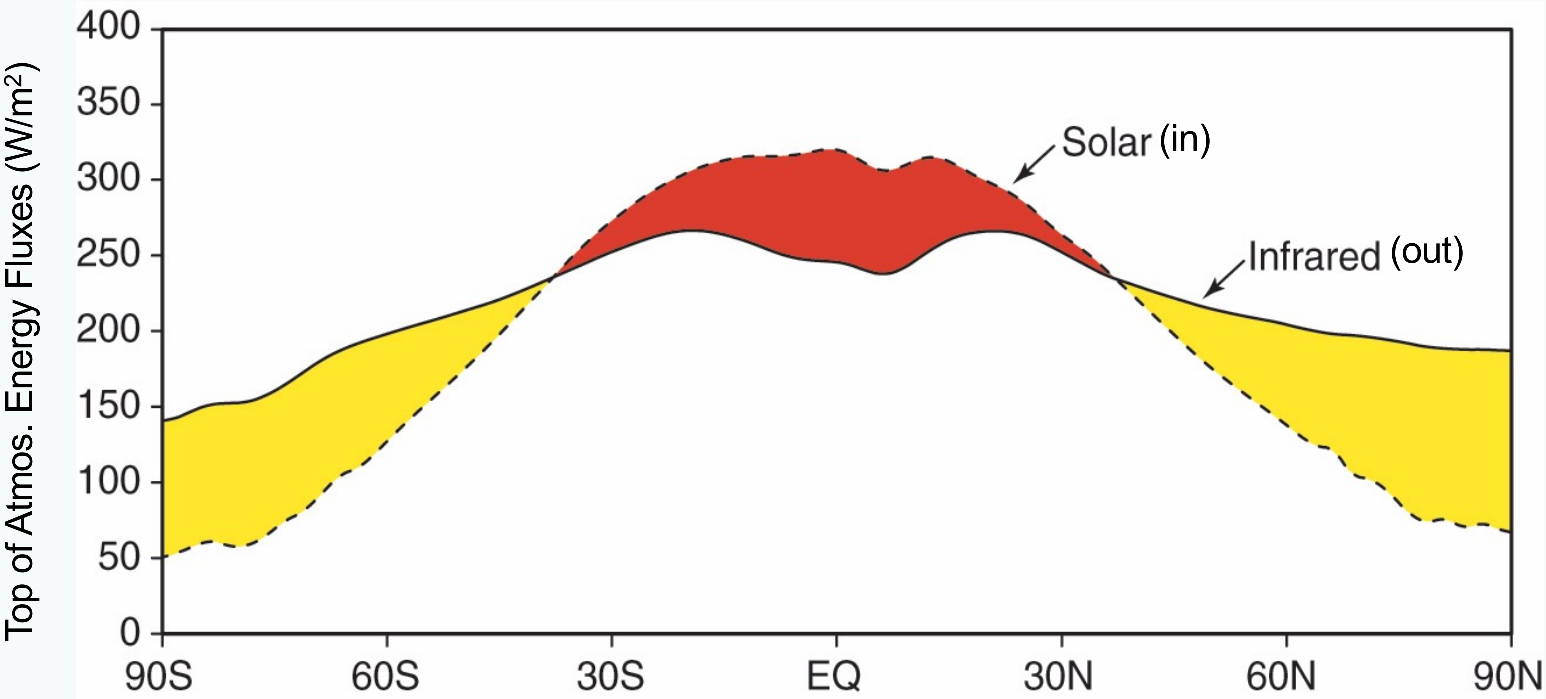


Less

More

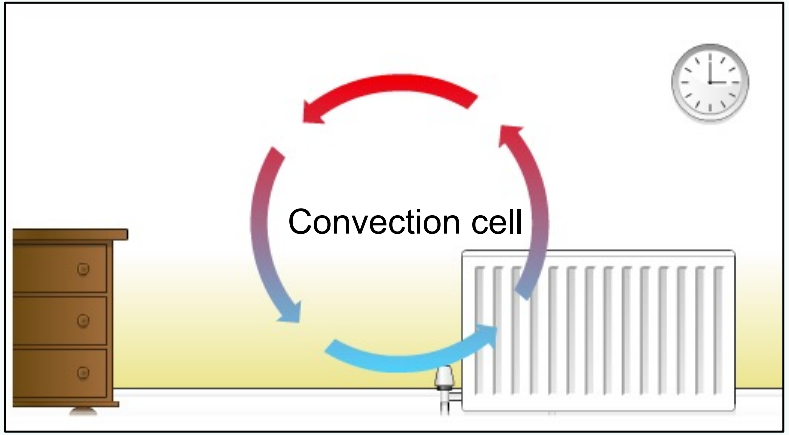
Energy Transfer

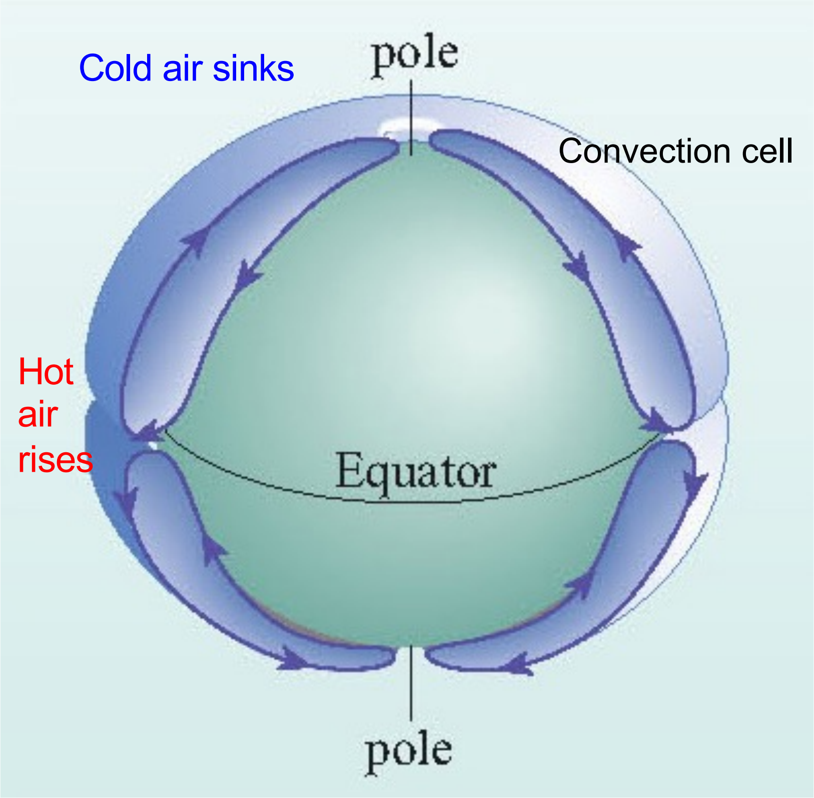
Uneven Heating:
Equator gets more sun radiation than the Poles



Redistribution of Heat

- Convection plays role
- Not as simple as Hadley's 1735 suggestion that convection cell extends from Equator to the Poles

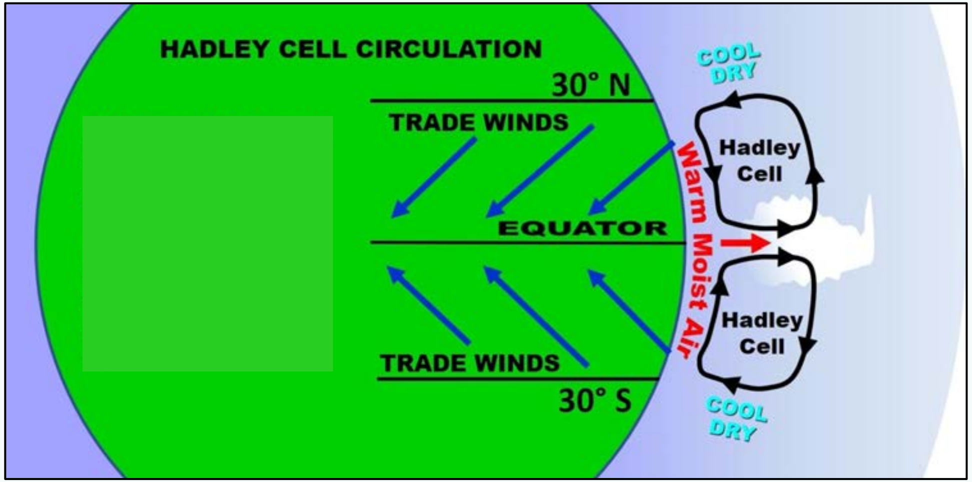




Does not account for the **Coriolis effect**

Tropical Hadley Cells

- Sun heats Equator
- Hot air rises
- Air masses move toward Poles
- Air masses diverge from north-south path due to Coriolis effect
- Cool dry air sinks at about 30° latitude (deserts)
- Still named Hadley cell



<u>Reminder:</u>

- Air rising (convective uplift) associated with clouds and rain (tropical rainforests)
- Air sinking (subsidence) associated with dry air (deserts)

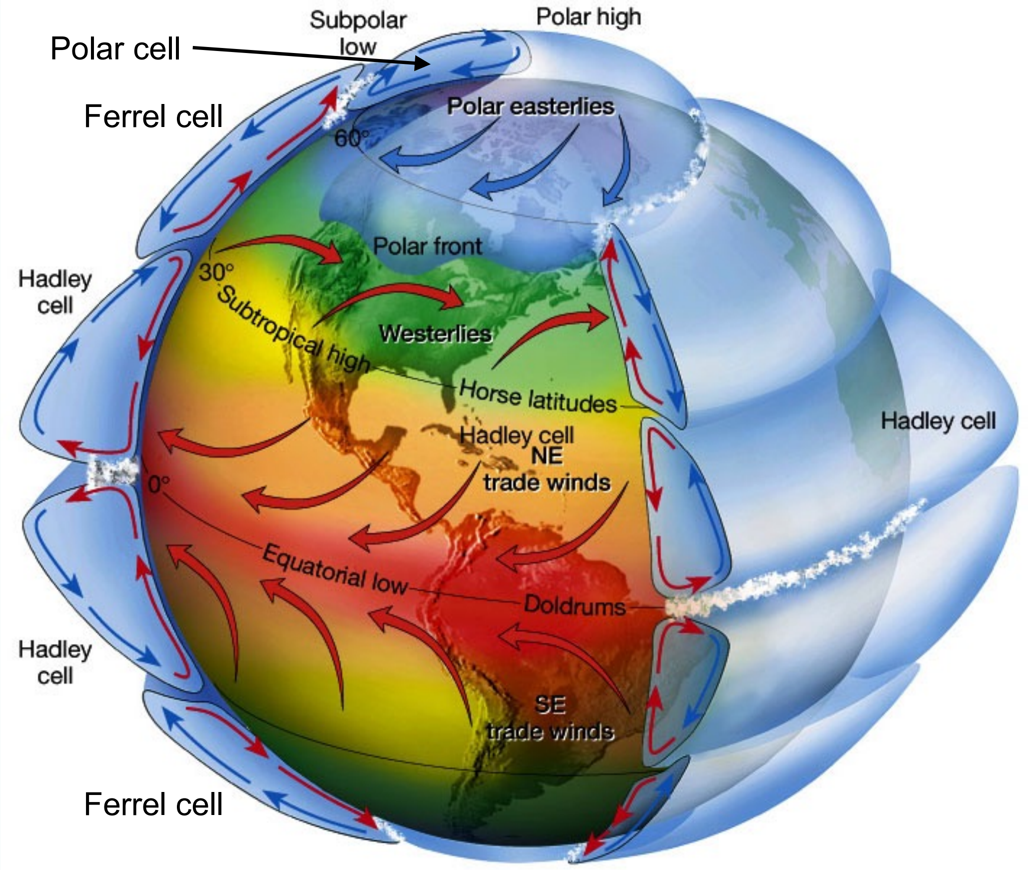
Convection cells and Surface Winds

Convection Cells:

- moist, warm air rises forming clouds
- cold, dry air subsides (compresses and warms)

Surface Winds:

- descending branch of cell reaches surface, forms surface winds that diverge due to Coriolis effect
- poleward and equatorward winds meet, air forced upward, maintains convective cells



Annual mean surface temperature

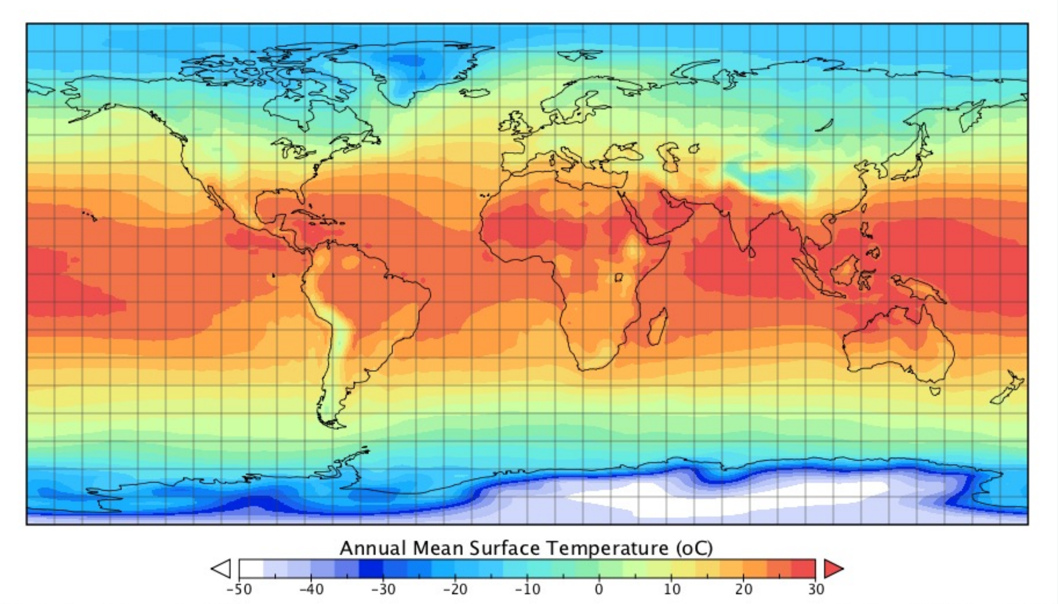
Warmest at the Equator

Coldest at the Poles

Antarctic colder than Arctic (isolated - less land mass to redistribute head)

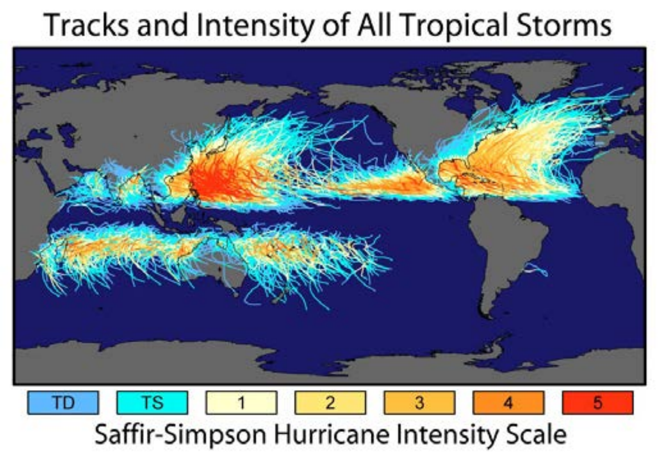
Colder at elevation

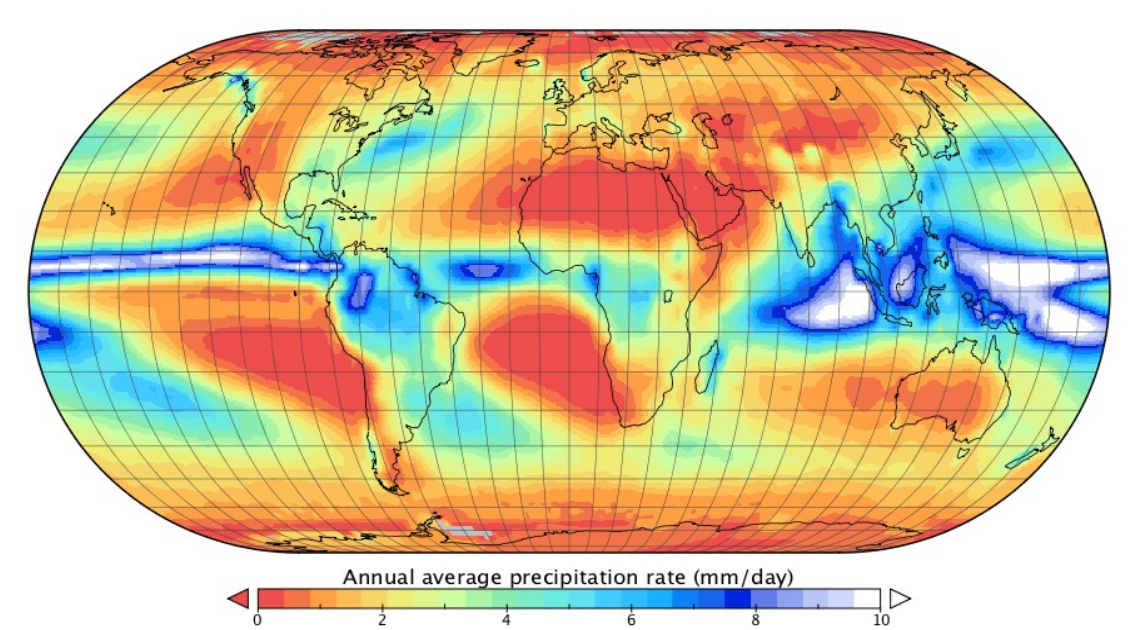
Canada colder than Europe



Annual mean rainfall/precipitation

- Most rain in Intertropical Convergence Zone (ITCZ) (convective uplift)
- Little rain at edge of tropics ~30^{o}N (subsidence)
- More rain over Equatorial oceans (storm tracks)





Circulation patterns not always stable

- Seasonal variation
- Interannual variability:
  - North Atlantic Oscillation
  - El Nino-Southern Oscillation
  - Extreme weather
- Longer timescale variability of 1000s of years (not the focus of this module)

Summary

1. Definition of climate
2. Energy transfer: radiation, convection, conduction
3. Simple energy balance model: blackbody radiation, albedo, greenhouse gases
4. Differential heating and redistribution of heat
5. Annual average climate variables (temperature, precipitation)

- *Next Lecture: Seasonality, Climate Change*