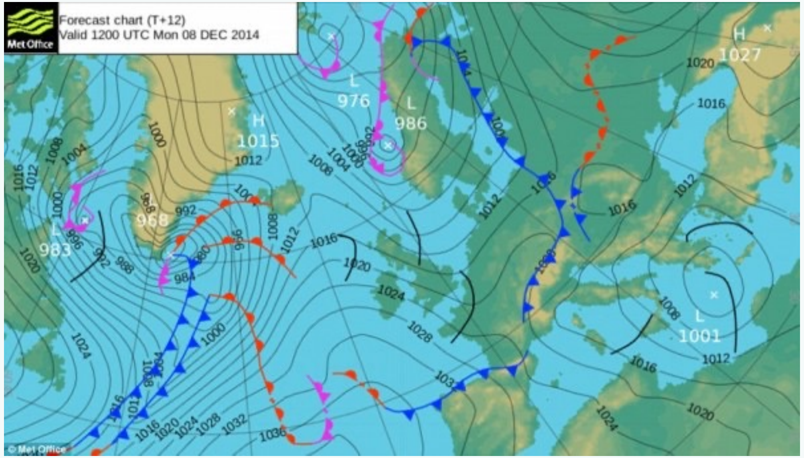
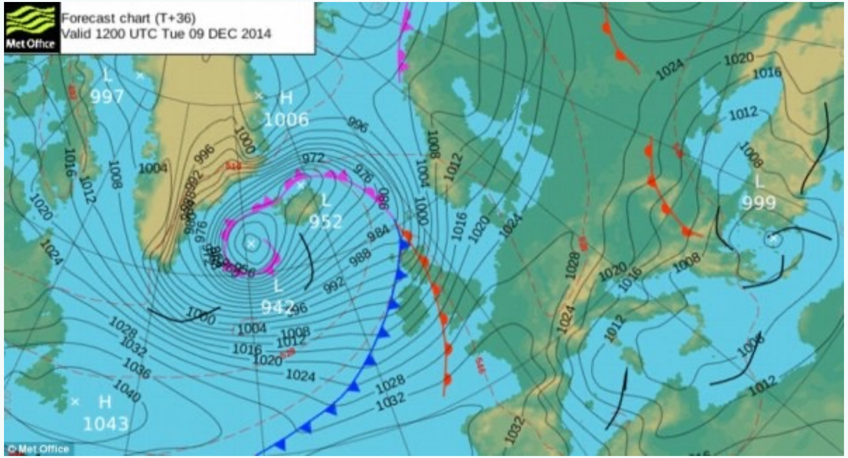
DEPARTMENT OF GEOGRAPHY

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?

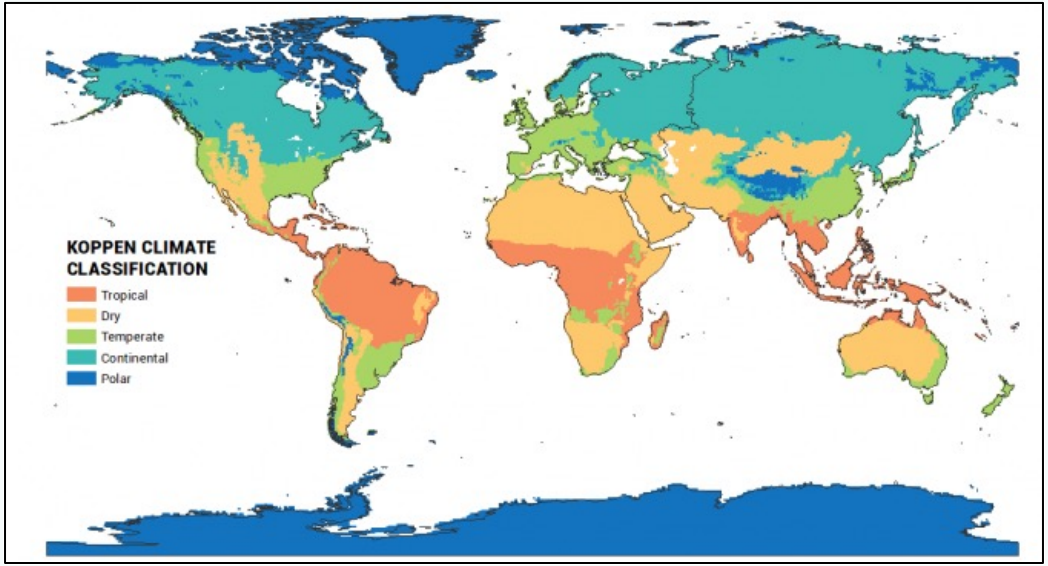
A. An occluded front
B. An anticyclone
C. A cyclone
D. Blocking

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

What is climate?

- **Average** atmospheric conditions
- Averages out weather, but not seasons
- The state of climate components or variables (temperature, precipitation)
- Climate measurements span modern to distant past (paleoclimate)
- Classified by land cover type, precipitation, temperature (Köppen)

Broad climate classifications



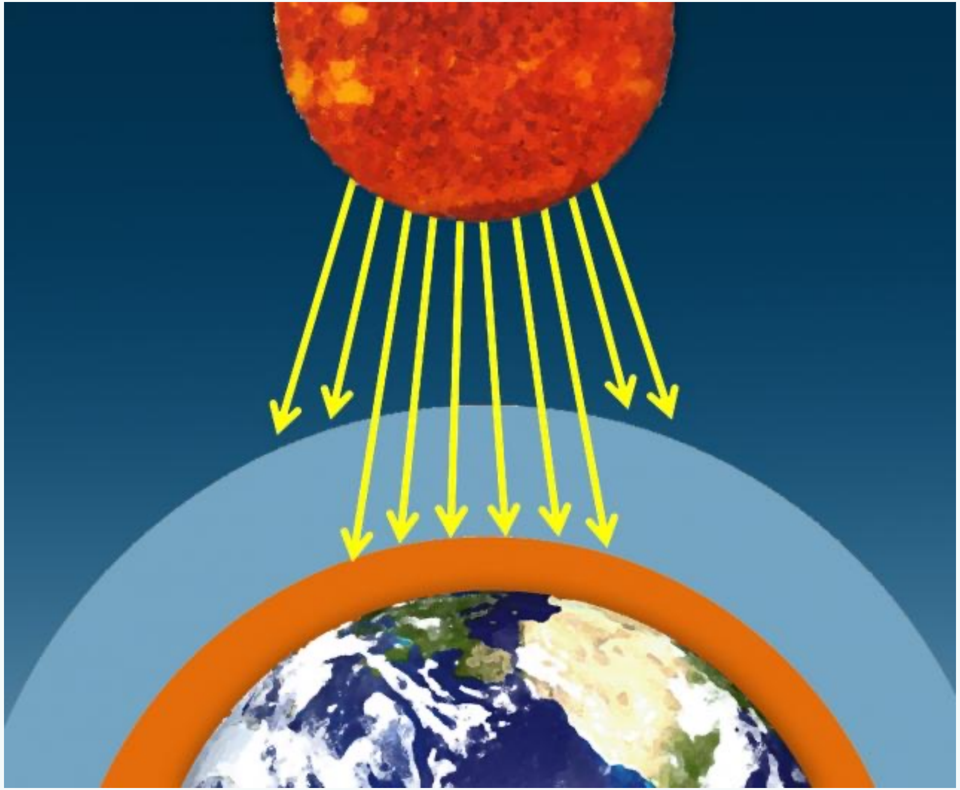
Source: https://earthhow.com/koppen-climate-classification/

WHAT CONTROLS CLIMATE?

Global Energy Budget

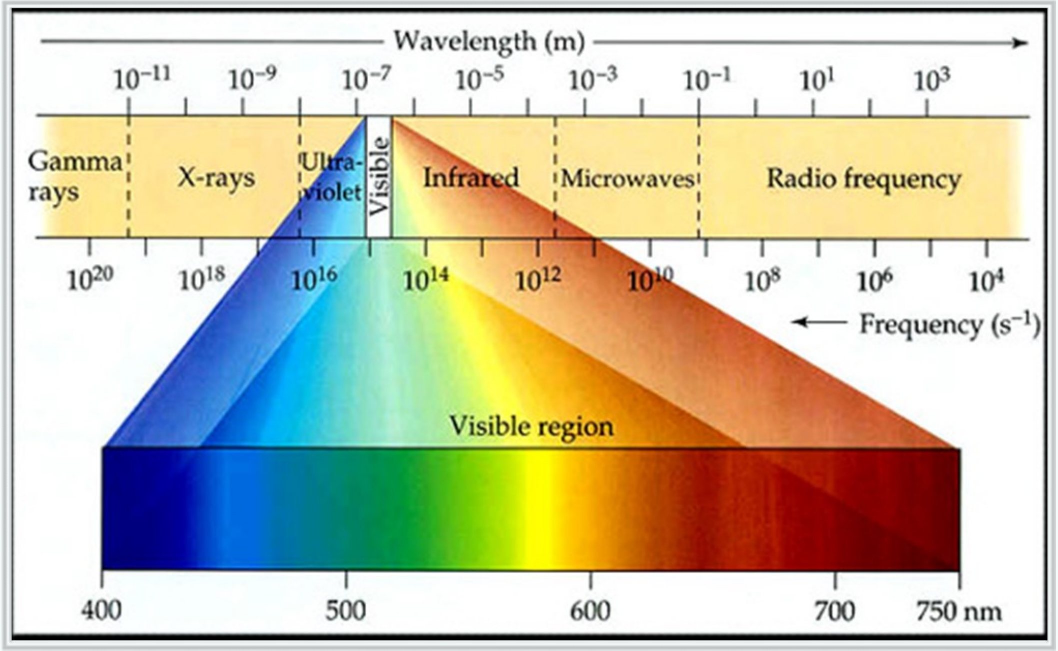
Energy Transfer

- 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

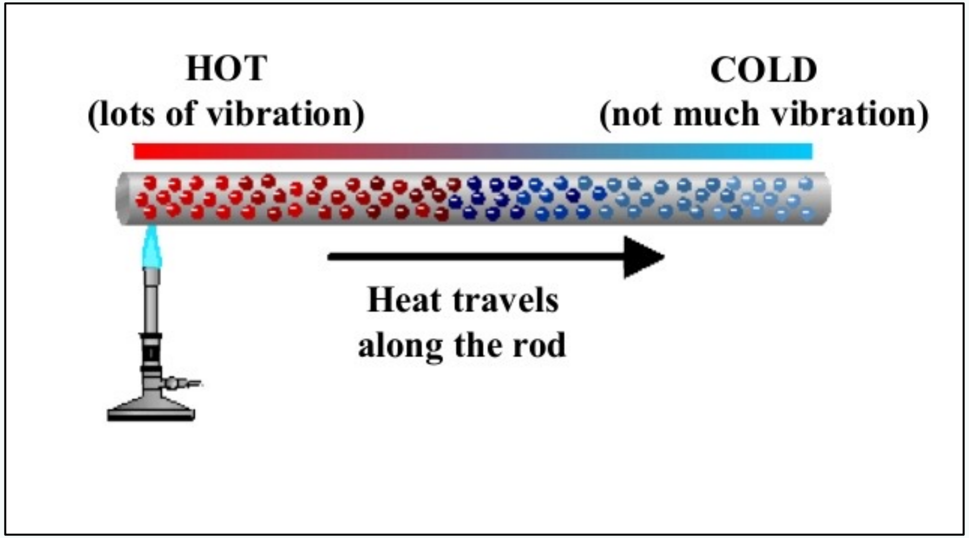


Energy inversely proportional to wavelength

Conduction

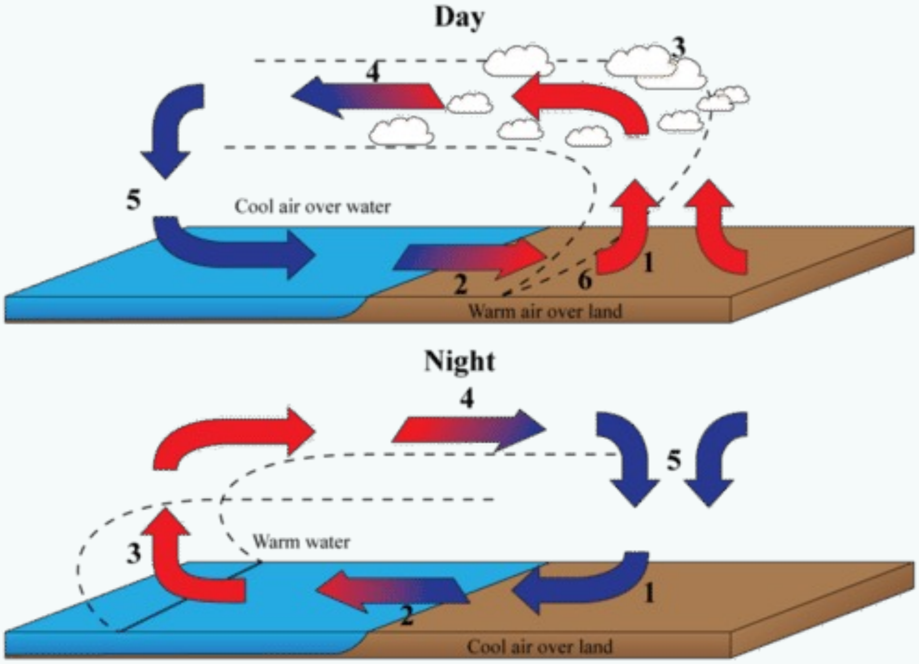
- Heat (energy) transfers from one molecule to next as molecules vibrate

- 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)

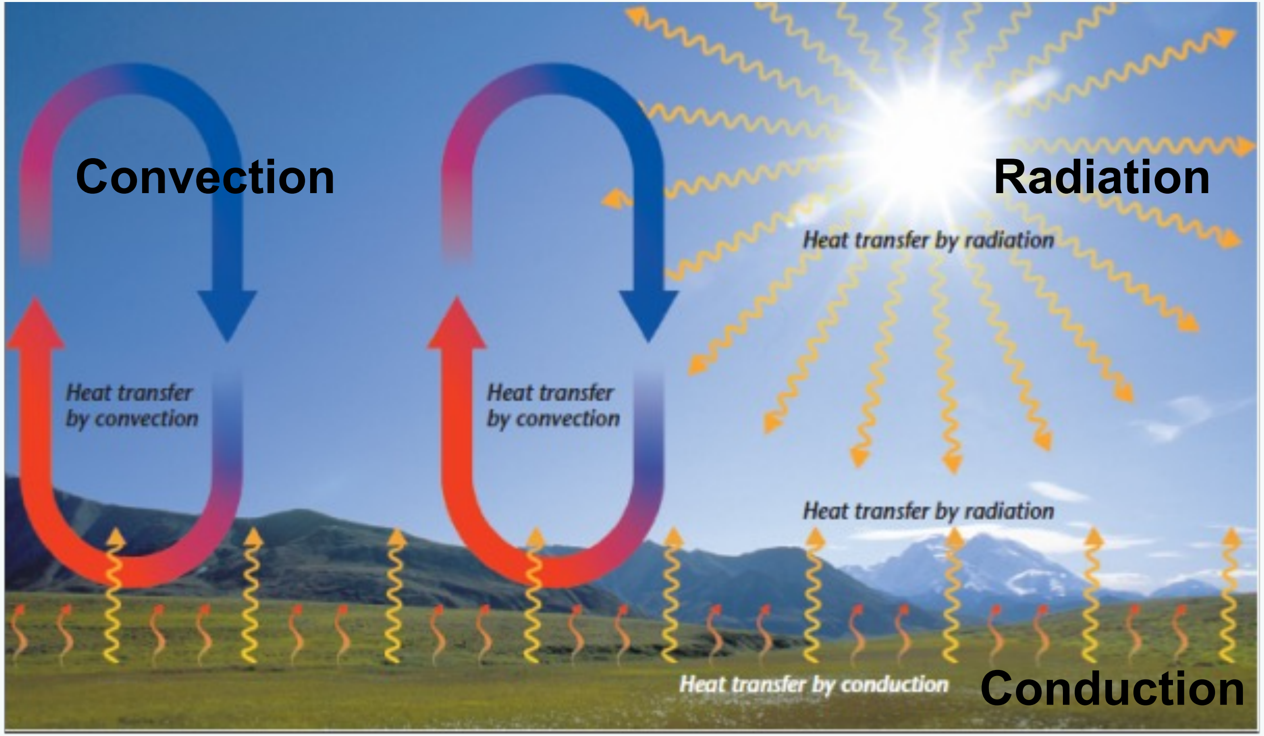


Convection

- 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
- Causes turbulence (fluid mixing) or an instability (uneven heating) in the atmosphere
- Moist convection leads to thunderstorms



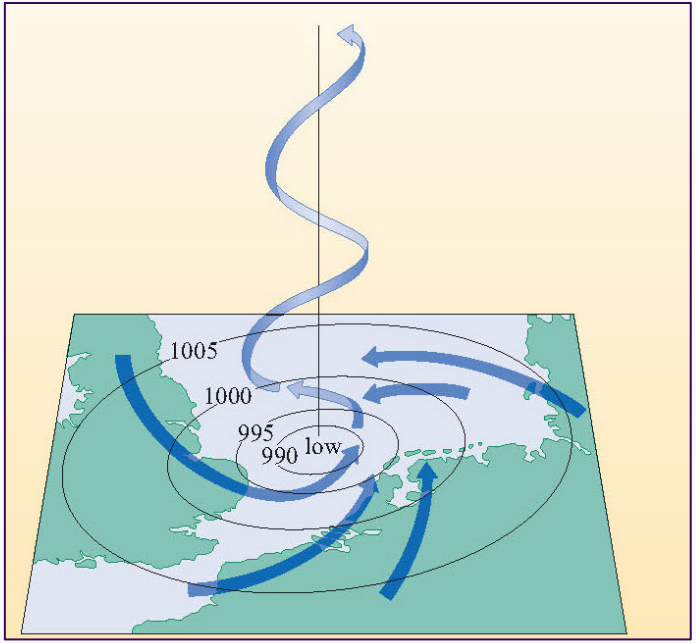
Heat Transfer in the Atmosphere



Test Your Understanding

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

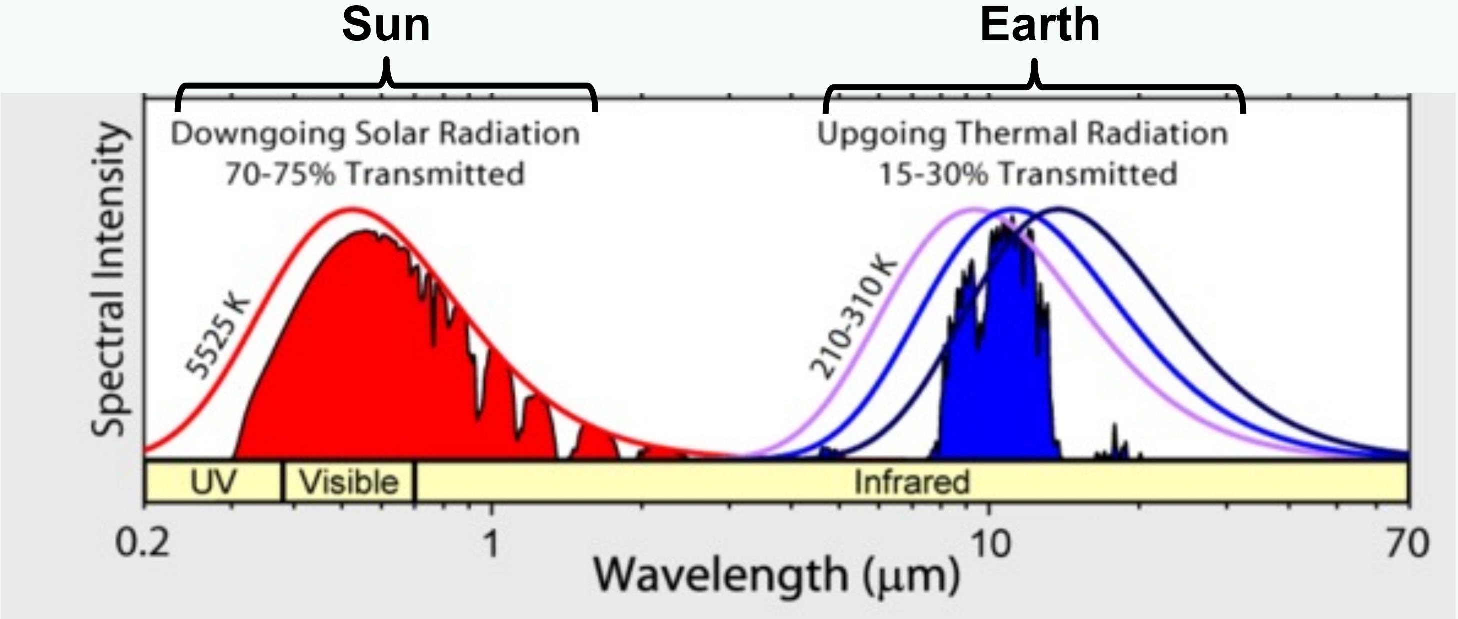
A. Conduction
B. Convection
C. Radiation
D. None of these



Longwave and Shortwave

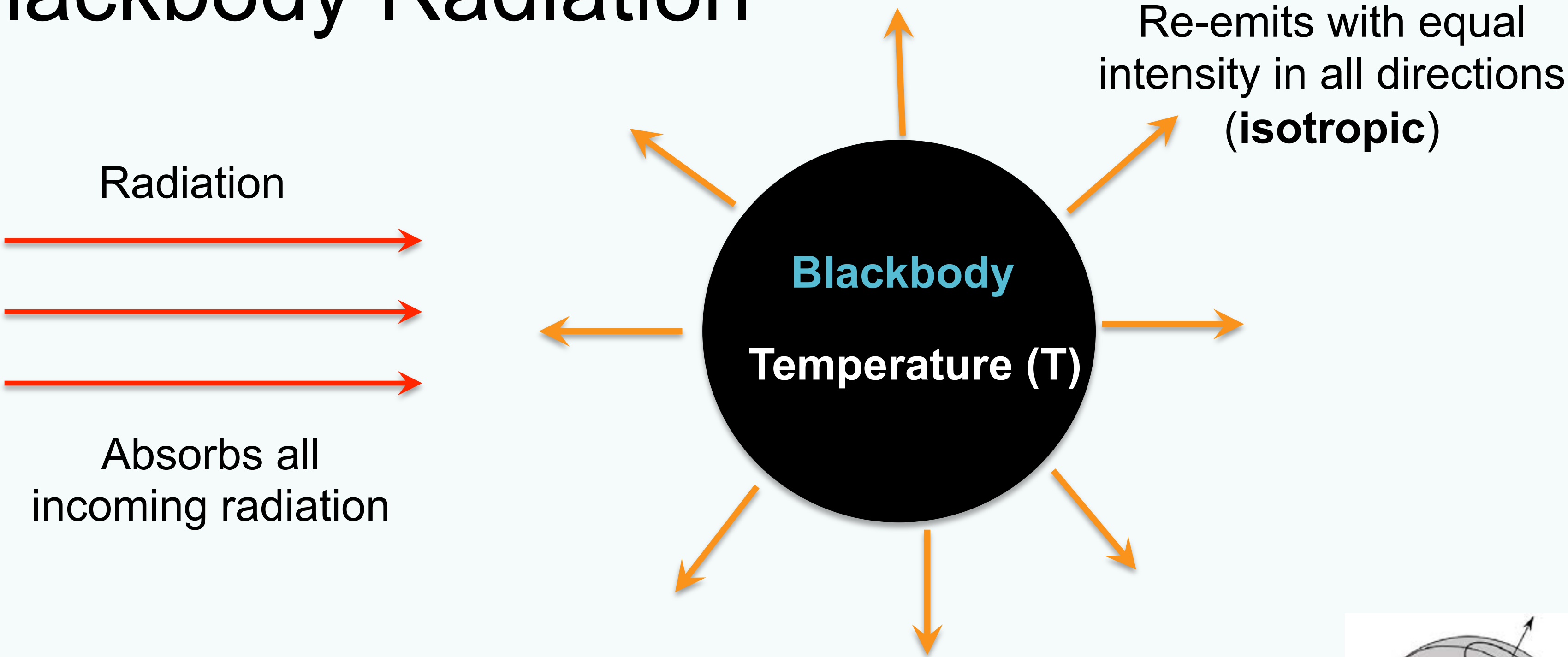
Radiation from the sun is in the shortwave (UV/visible)

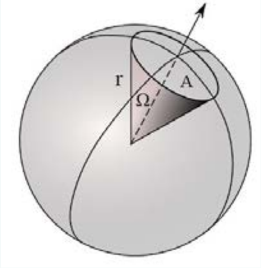
Radiation from the Earth is in the longwave (infrared)



Occupy distinct regions on the electromagnetic spectrum

Blackbody Radiation





- **Radiance**: power emitted by a blackbody
  radiation flux per unit area per unit solid angle [$W/m^2/sr$]
- **Spectral radiance**: Radiance per unit wavelength [$W/m^2/sr/nm$]

Blackbody Radiation

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

- Tells us how much radiation emitted at a certain wavelength for a body of a certain temperature

Stefan-Boltzmann Law

- Relates power radiated from a blackbody to its temperature
- Total energy radiated by a blackbody with temperature T is proportional to the 4th power of T (T^4)
- This spectral intensity (I) over all directions and wavelengths is:

$$\boxed{I = \sigma T^4}$$

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

- I is in power per unit area or Watts per square metre (W/m^2)

Test Your Understanding

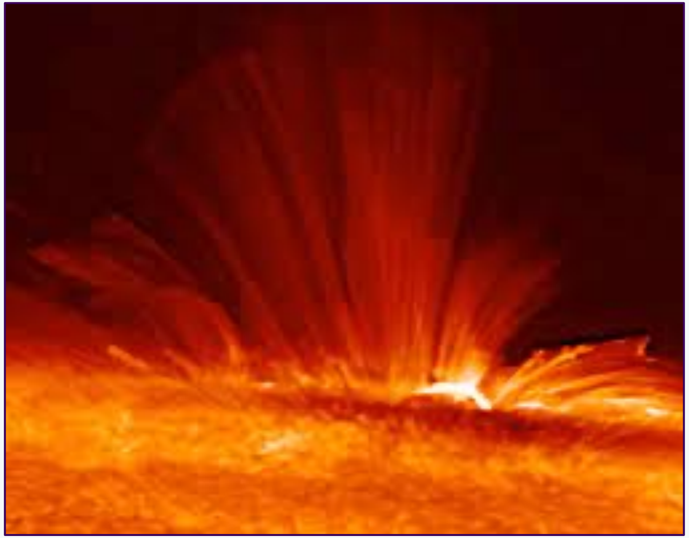
The Stefan-Boltzmann constant is 5.67×10^{-8} W m^{-2} K^{-4} and the temperature of the sun, a blackbody, is 5778 K. What is the energy radiated from the surface of the sun?

A. 5778 W/m^2

B. 63000 kW

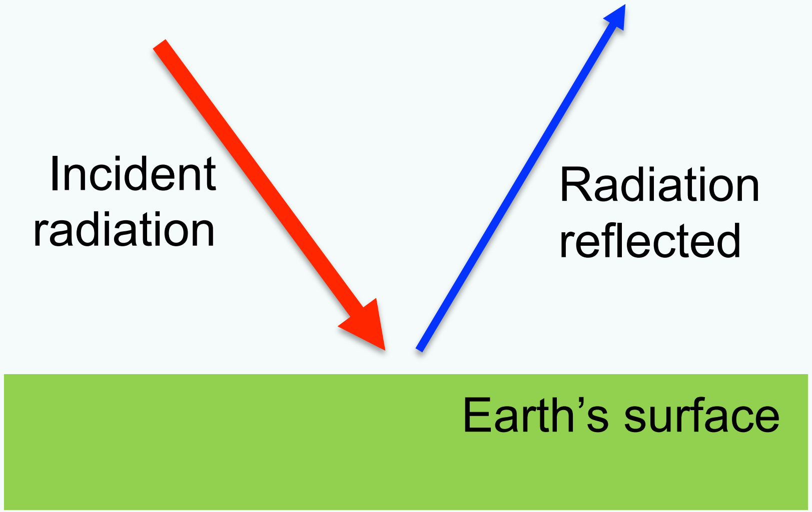
C. 63000 kW/m^2

D. 0.0032 W/m^2



Radiation Modifiers: **Albedo**

- Ratio of reflected to incident (incoming) radiation
- Ranges from 0 to 1
- Represent with the symbol alpha (α)

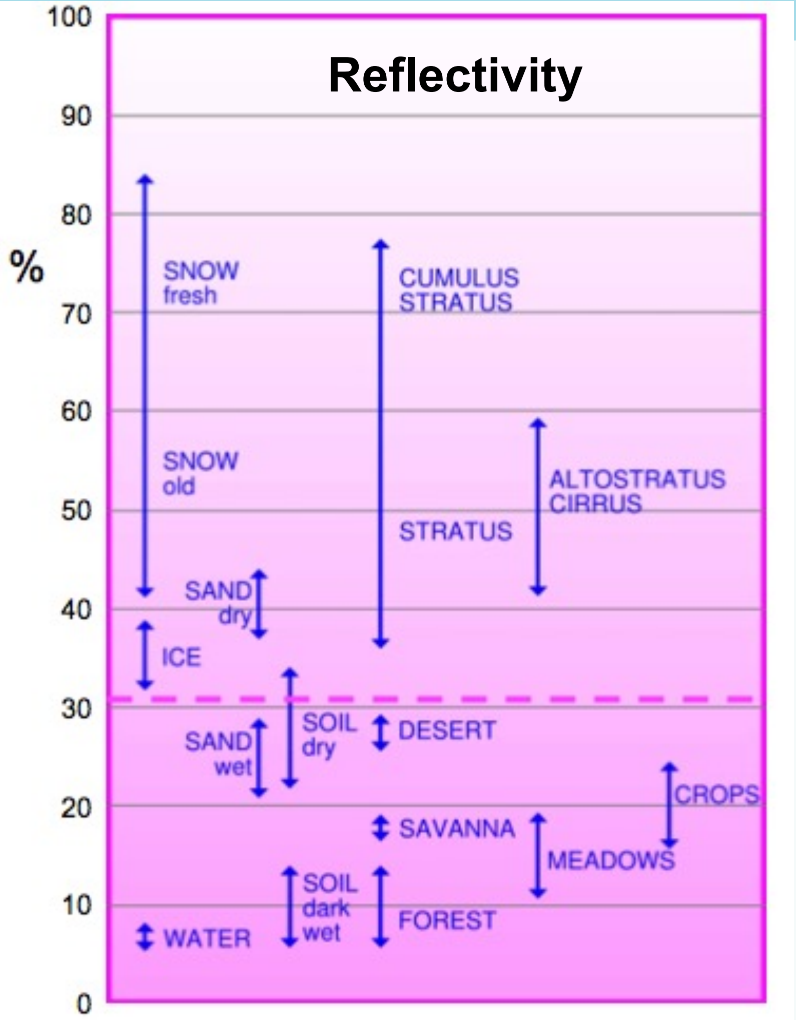


Earth’s Albedo

- Clouds, ice, reflective land surfaces like deserts increase Earth’s albedo (α)

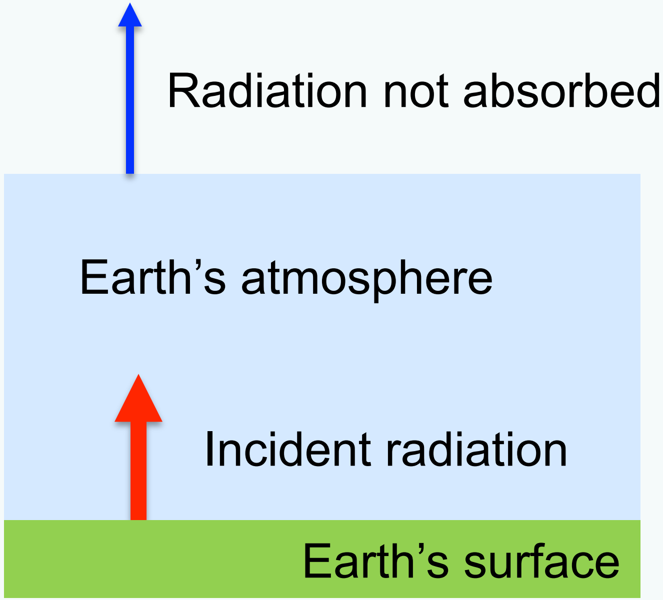
Albedo Properties of Earth’s surface

- Reflectivity is equivalent to albedo
- Earth has a global average albedo (α) of **0.3**
- 30% of incident (incoming) sunlight reflected



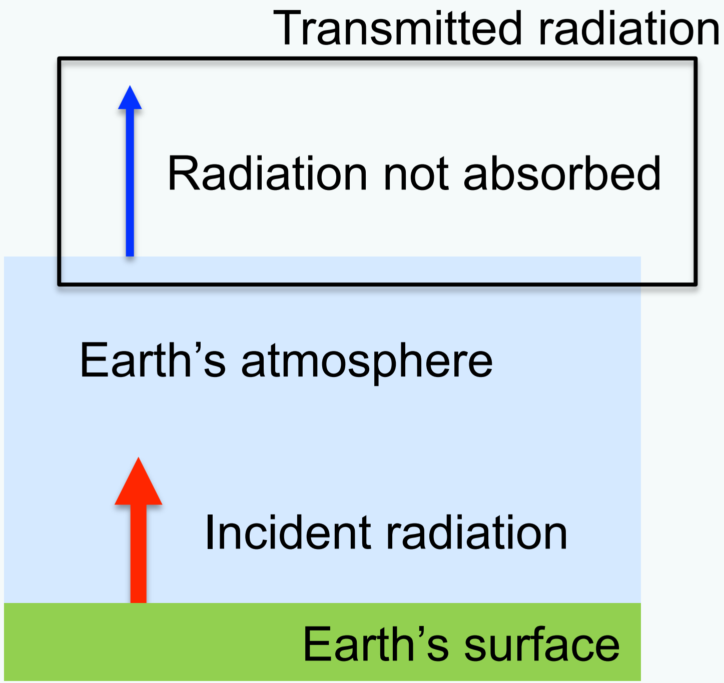
Radiation Modifiers: **Emissivity**

- Amount of radiation absorbed by a body compared with that of a blackbody
- Ranges from 0 to 1
- Represent with the symbol epsilon (ε)
- Called a grey body if $\varepsilon < 1$
- Earth's emissivity is ~0.77

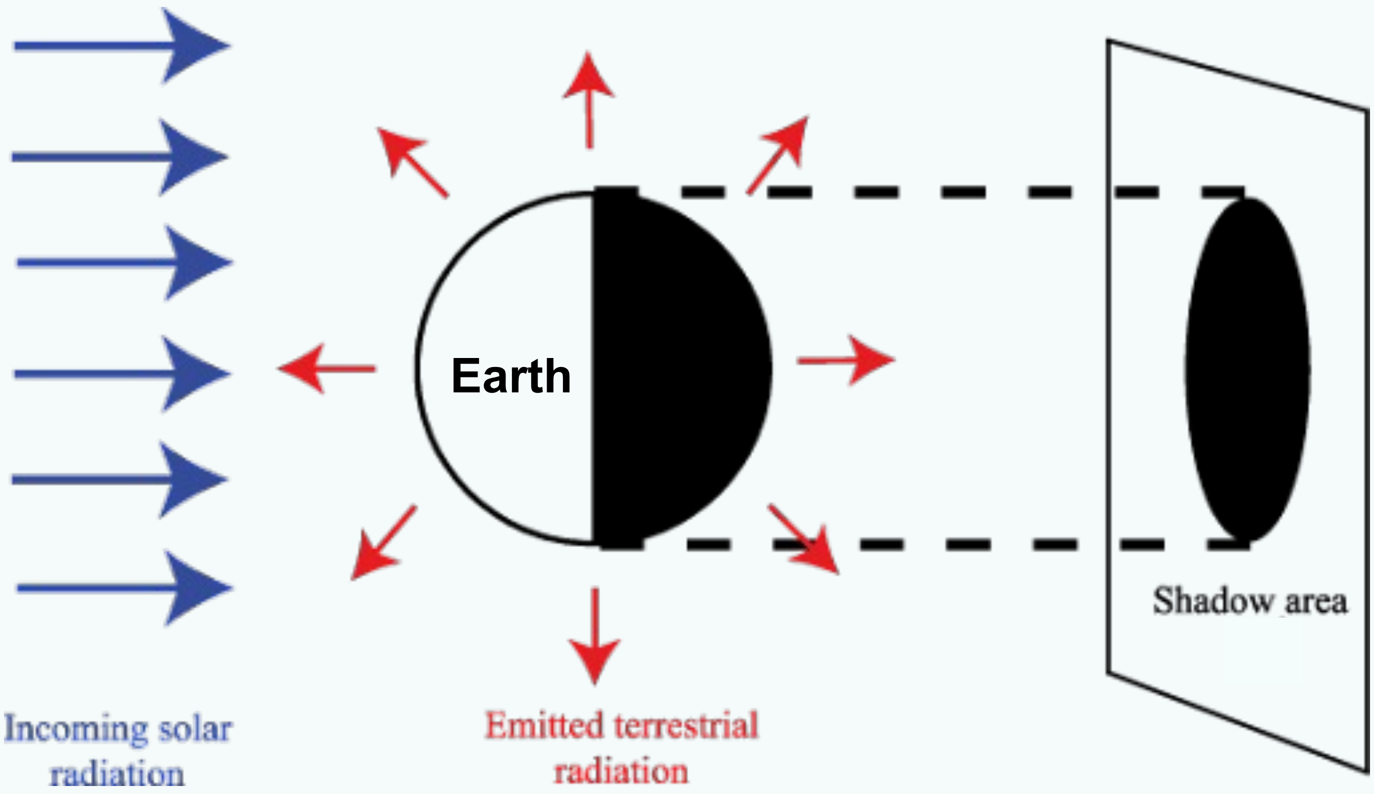


Radiation Modifiers: **Transmittance**

- Amount of radiation not absorbed by grey body
- Ranges from 0 to 1
- $1 - \varepsilon$



Incoming radiation

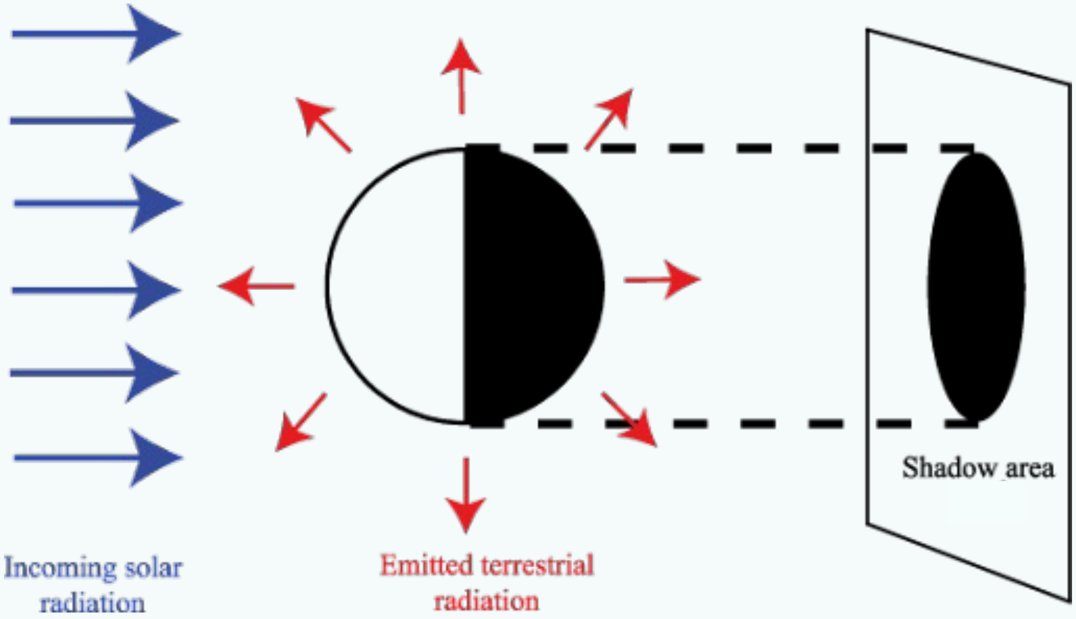


Shadow area:

πR^2

Incoming radiation

Sun's energy is **1366 W/m²** (the solar constant or $\mathbf{S_o}$)



S_o

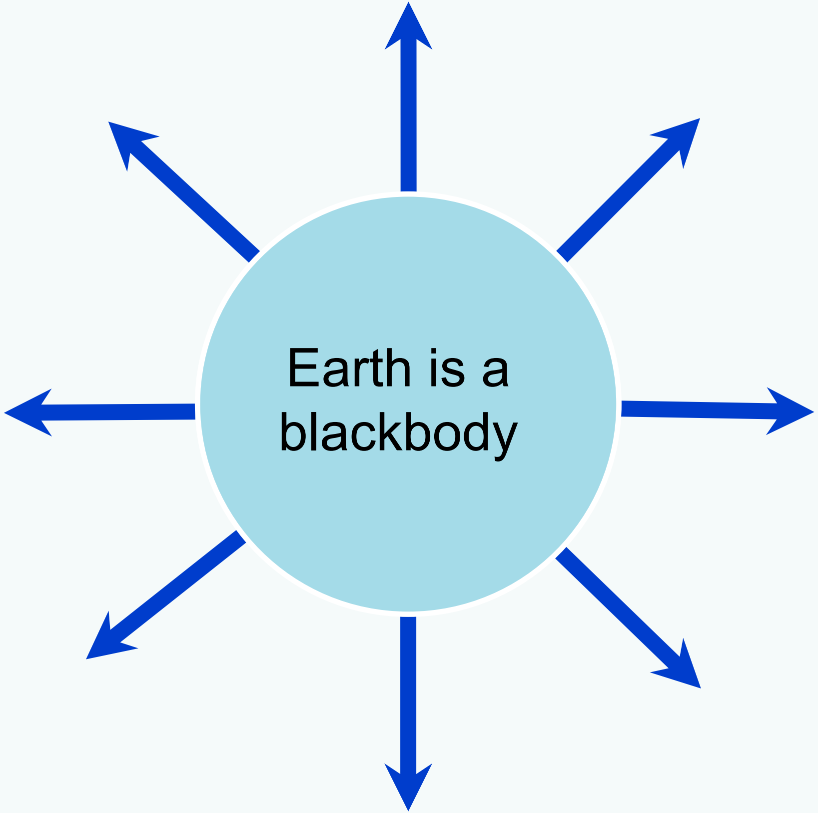
Shadow area:

πR^2

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 $= (\pi R^2)/(4\pi R^2)$
  $= 1/4$
- Amount of sun's radiation absorbed by Earth: $1 - \alpha$

Outgoing radiation



Earth is a blackbody that emits longwave radiation

Energy proportional to its temperature:

$$\sigma T^4$$

Steady State

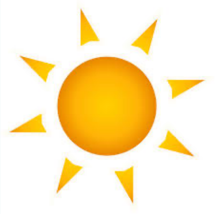
- Earth's climate system, unperturbed, is in a (quasi-) steady state:

Energy In = Energy Out

(Incoming radiation = Outgoing radiation)

- Space is a vacuum, so only energy transferred is electromagnetic radiation

We have everything we need to calculate temperature



Energy in = Energy out

$$S_o(1-\alpha)/4 = \sigma T^4$$

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

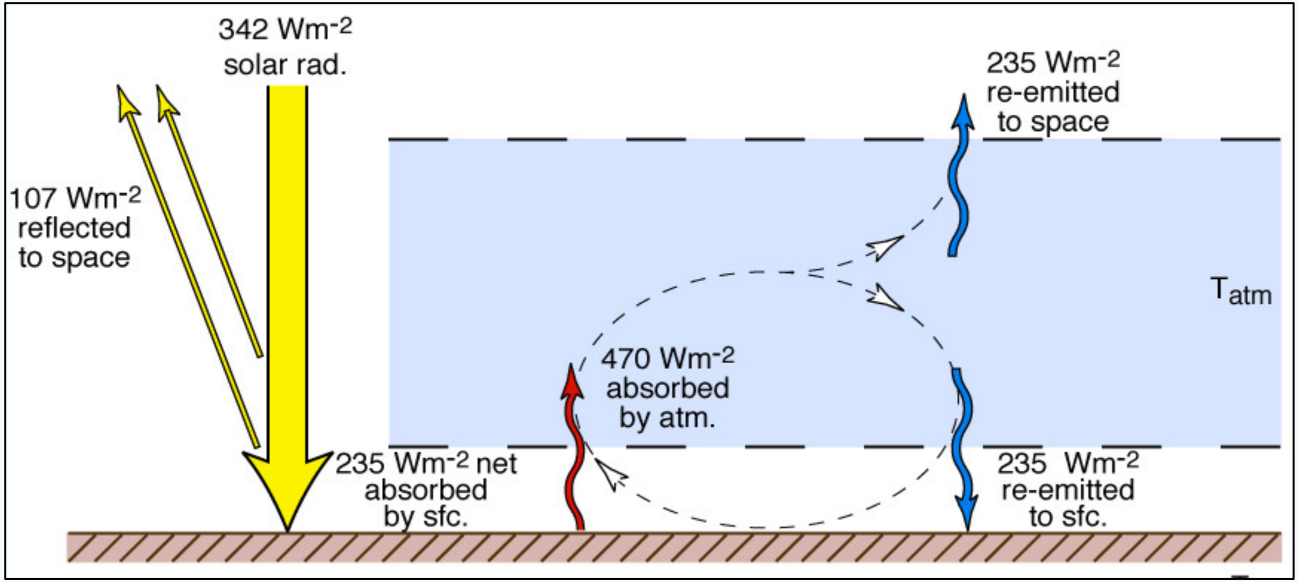
T = 255 K = -18^{o}C

Too cold to be habitable. Actual temperature is +15^{o}C.

Greenhouse Gases (GHGs)

Earth's atmosphere is a grey body ($\varepsilon \sim 0.77$) due to GHGs

Absorbs upwelling longwave radiation from surface and re-emits in all directions



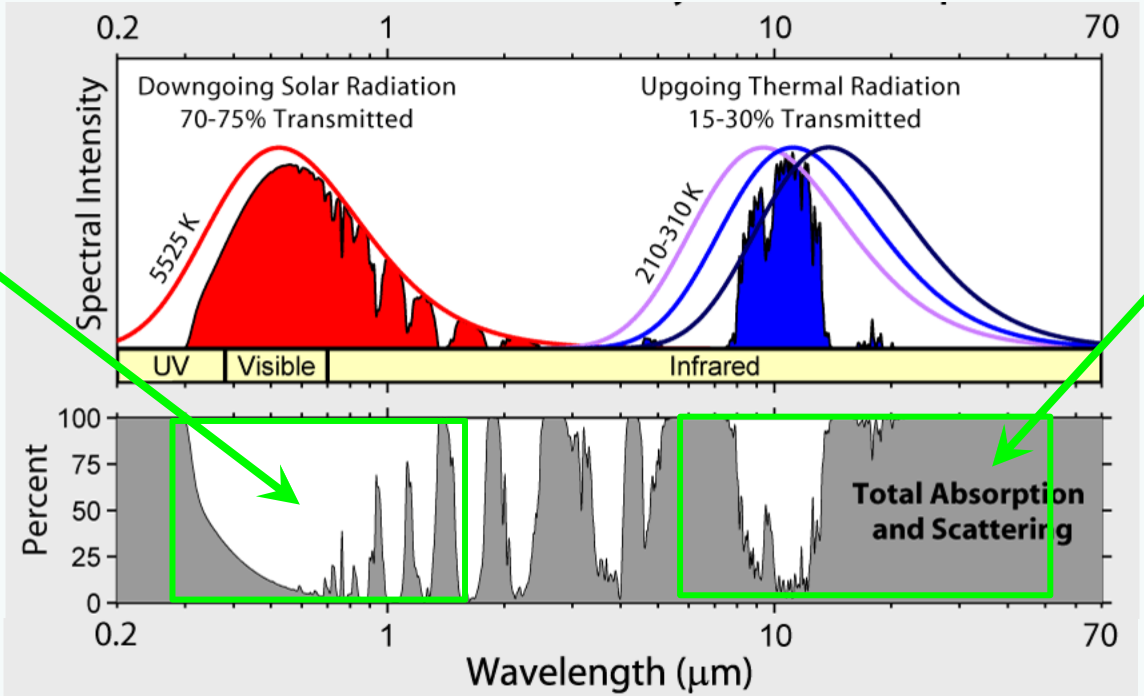
GHGs maintain Earth's surface T at 288 K (15^{o}C)

sfc. = surface

Longwave and Shortwave Radiation

Earth's atmosphere transparent to sun's shortwave radiation, but absorbs most longwave radiation

Majority of shortwave passes through atmosphere

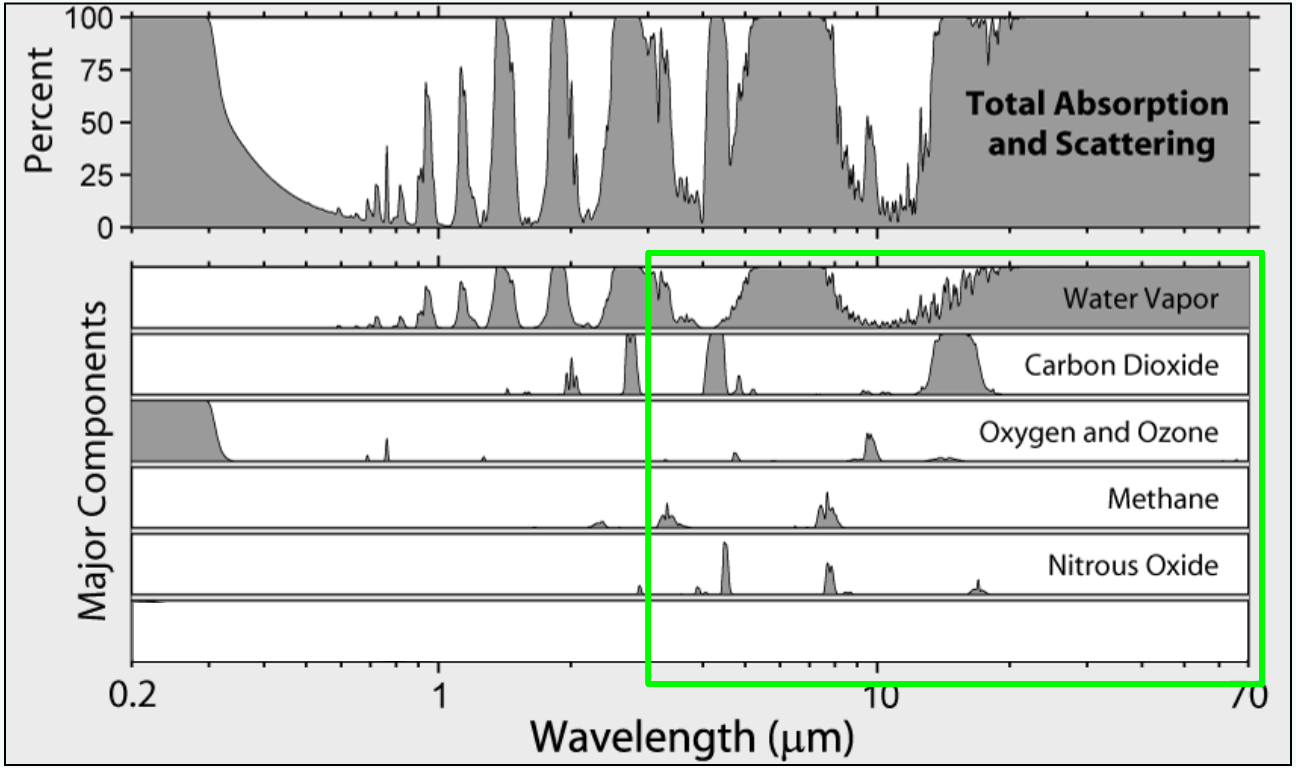


Very little longwave escapes

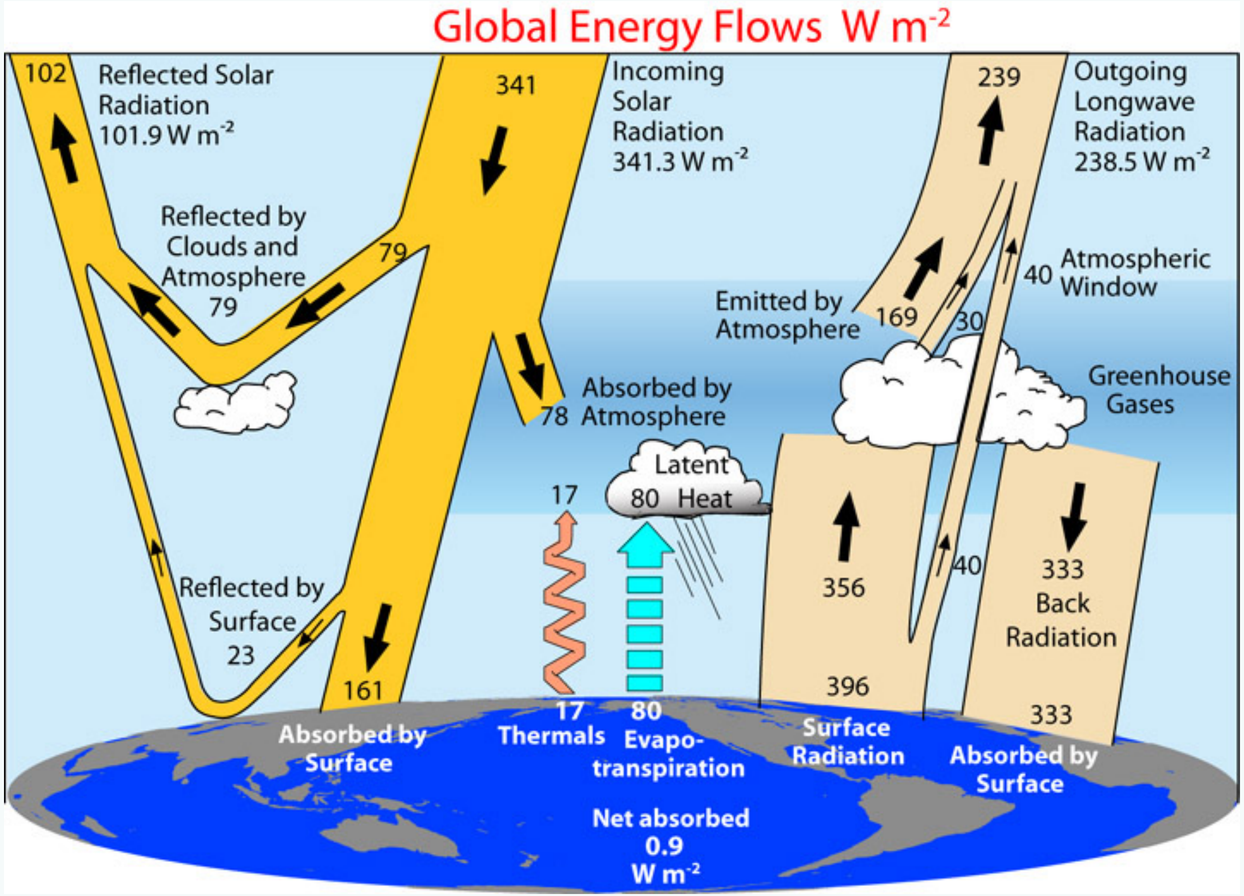
Absorption of Radiation by Greenhouse Gases

Dominant GHGs:

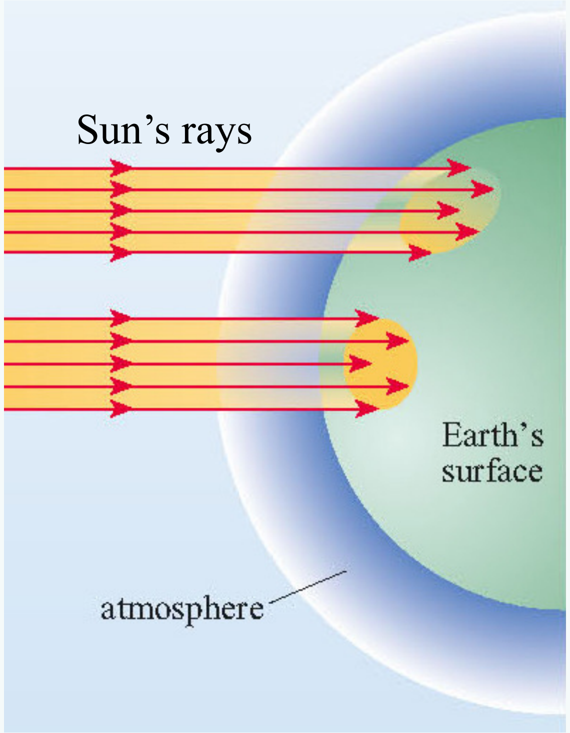
- water vapour
- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)



Putting it all together: Earth's Energy Balance



Equator gets more sun radiation than the Poles



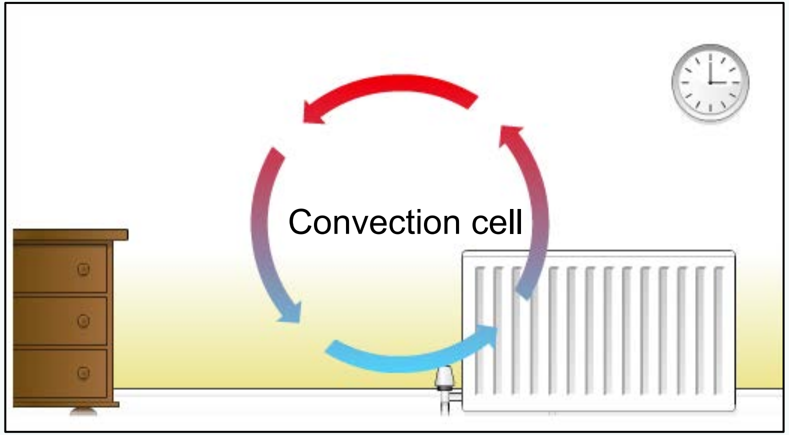
Less

More

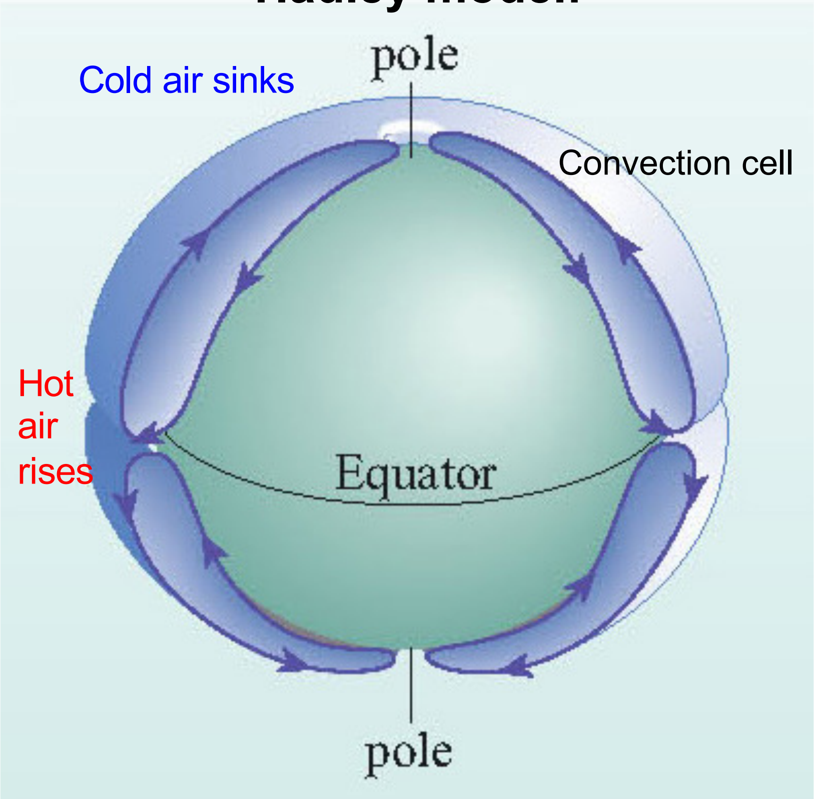
Energy Transfer

Redistribution of Heat

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



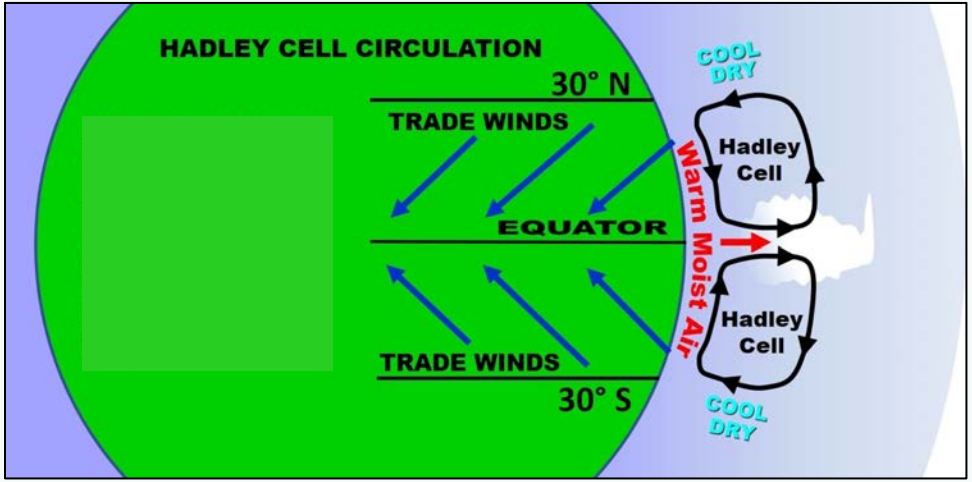
Hadley model:



Does not account for the **Coriolis effect**

Tropical Cells

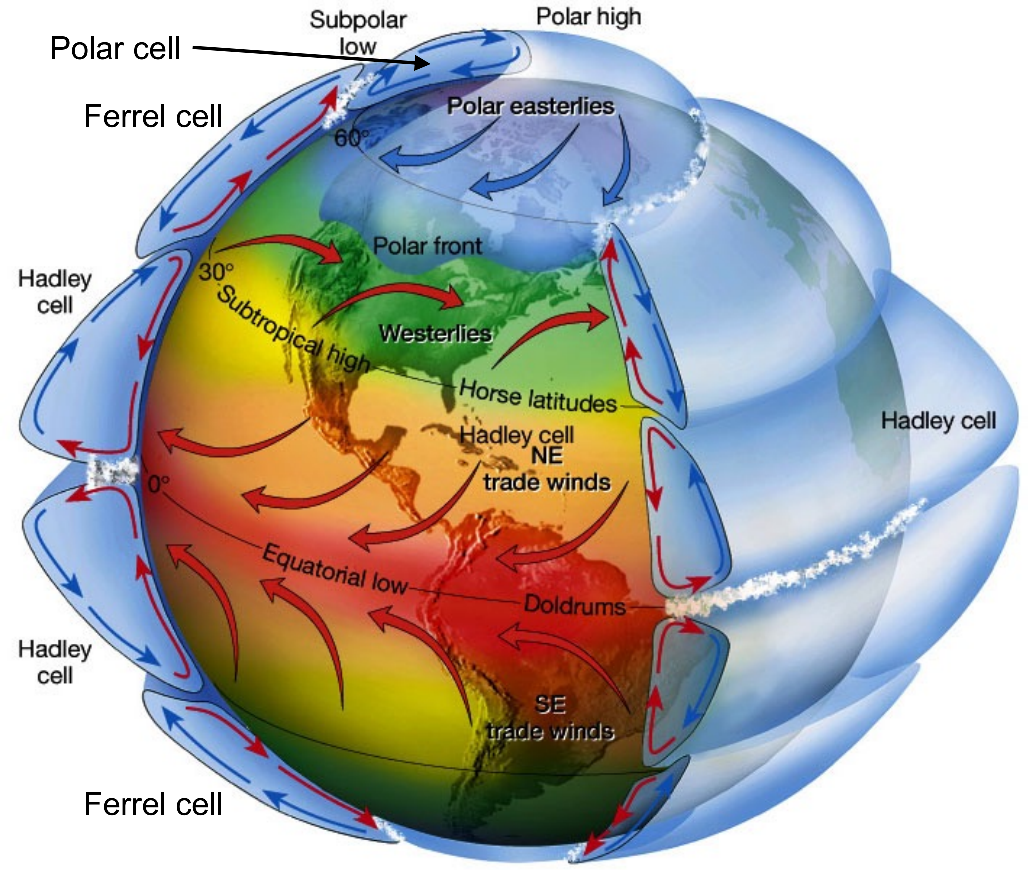
- Sun heats Equator
- Hot air rises
- Air masses move toward Poles
- Air masses diverge from north-south path due to Coriolis effect
- Cool dry air sinks at about 30^{o} latitude (deserts)
- Still named Hadley cells



Global Cells and Surface Winds

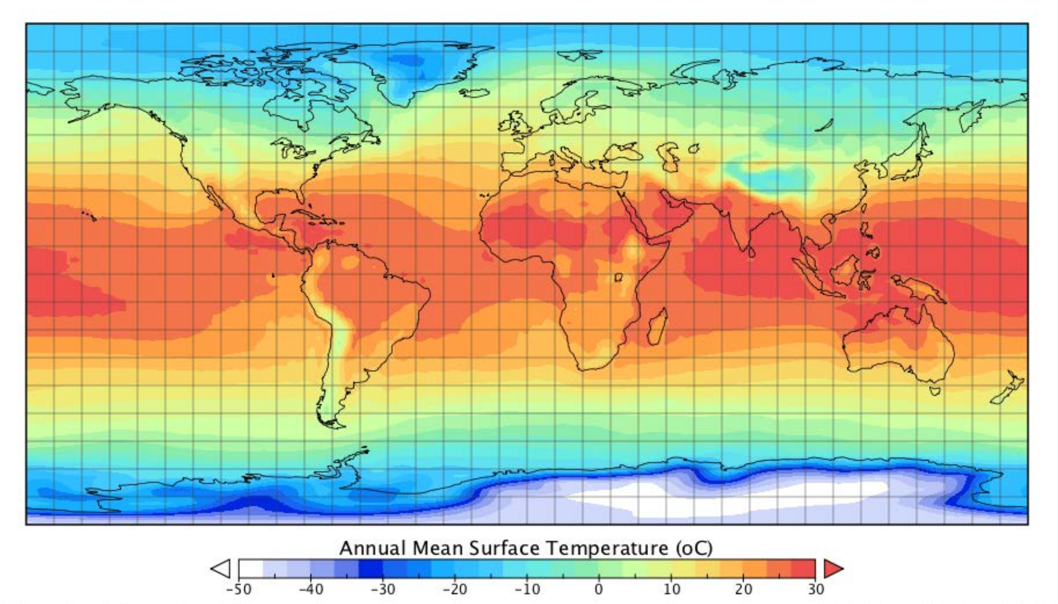
Convection Cells:
- moist, warm air rises, forms clouds
- cold, dry air subsides (warms)

Surface Winds:
- subsiding 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



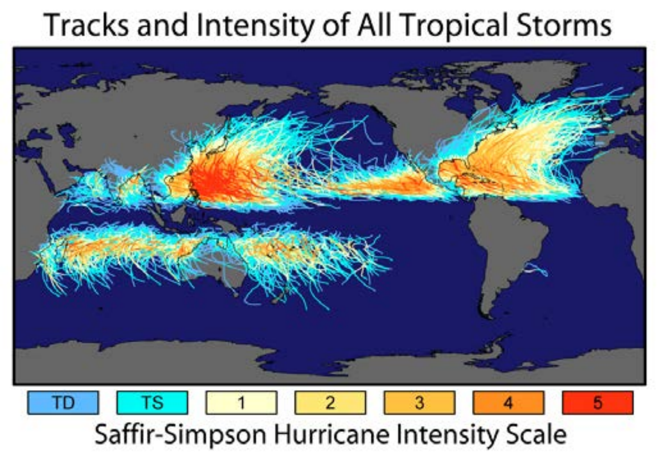
Annual mean surface temperature

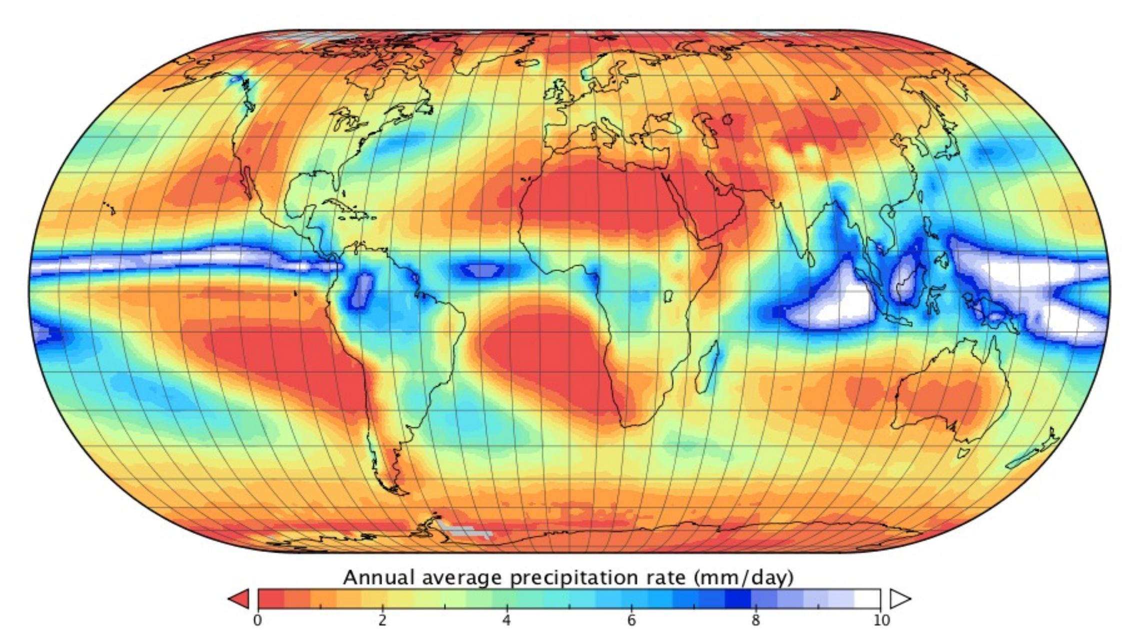
- Warmest at the Equator
- Coldest at the Poles
- Antarctic colder than Arctic (isolated - less land mass to redistribute head)
- Colder at elevation
- Canada colder than Europe



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)





Summary

1. Climate definition
2. Energy transfer: radiation, convection, conduction
3. Earth's energy balance: incident sunlight, blackbody radiation, albedo, greenhouse gases
4. Differential heating and redistribution of heat
5. Annual average climate variables (temperature, precipitation)

- *Next Lecture: Seasons, Climate Change*