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.co m/koppen-climateclassification/



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



- Radiance: power emitted by a blackbody radiation flux per unit area per unit solid angle [W/m²/sr]
- **Spectral radiance**: Radiance per unit wavelength [W/m²/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:
$$B(\nu,T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}$$

B: spectral radianceh, c, k: constantsv: frequency of lightT: 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 (T⁴)
- This spectral intensity (I) over all directions and wavelengths is:

where $\sigma = 5.67 \times 10^{-8}$ 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/m²)

 $I = \sigma T^4$

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/m²
- B. 63000 kW
- C. 63000 kW/m²
- 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 ε

Transmitted radiation

Radiation not absorbed

Earth's atmosphere

Incident radiation

Earth's surface

Incoming radiation



Incoming radiation

Sun's energy is **1366** W/m^2 (the solar constant or S_o)



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: 1α

Outgoing radiation Earth is a blackbody

Earth is a blackbody that emits longwave radiation

Energy proportional to its temperature:

 σT^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

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



$$T = \sqrt[4]{\frac{S_0(1-\alpha)}{4\sigma}}$$

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

Greenhouse Gases (GHGs)

Earth's atmosphere is a grey body ($\epsilon \sim 0.77$) due to GHGs Absorbs upwelling longwave radiation from surface and re-emits in all directions



Longwave and Shortwave Radiation

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



Absorption of Radiation by Greenhouse Gases

Dominant GHGs:

- water vapour
- carbon dioxide (CO₂)
- methane (CH₄)
- nitrous oxide (N₂O)



Putting it all together: Earth's Energy Balance



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 Cells

- Sun heats Equator
- Hot air rises
- Air masses move toward Poles
- Air masses diverge from northsouth path due to Coriolis effect
- Cool dry air sinks at about 30° 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°N (subsidence)
- More rain over Equatorial oceans (storm tracks)

Tracks and Intensity of All Tropical Storms





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