Major Deep Sea Currents (>2 km)

Meridional energy imbalance drives circulation. What causes meridional energy imbalance?

1. High angle of incidence in tropics, low angle at poles. Solar flux spread over larger planetary surface area at poles than at equator.

Effect of latitude (angle of incidence) on insolation?

\[ I = (1-a) S \cos Z \]

- \( I = \text{insolation} \)
- \( S = 1370 \, \text{W/m}^2 \)
- \( a = \text{albedo} \)
- \( Z = \text{zenith angle (in radians)} \)
- \( \approx \text{lat}^\circ \times \pi/180 \)
2. High albedo at poles, low albedo at equator.

3. Outgoing flux determined by surface temperature via Stefan-Boltzman Law.

**Energy flux = \( \sigma T^4 \)**

Heat transport via ocean and atmosphere tends to equalize this temperature, such that outgoing longwave flux gradient is less steep than the incoming shortwave gradient.

**Equator-to-pole heat flow**

50% by atmosphere, 50% by oceans
Atmosphere Circulation

**Latent heat transport**: describes heat moved by transport and phase changes of water.

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**Sensible heat transport**: describes heat moved by motion of air.

**Air Pressure** - column of air at sea level weighs 1 atm or 1000 mb (millibars)

**Atmosphere Pressure Gradients**

- **High pressure** - sinking due to cooling
- **Low pressure** - rising due to heating

Wind - air moving from high to low pressure
Large Scale Atmospheric Circulation

Air rises at equator and at polar front (~60° latitude)

**Rising air cools, moisture condenses - rain or snow**

Air sinks at 30° and 90° latitude

**Sinking air warms, holds more moisture - no precipitation**

![Diagram of Large Scale Atmospheric Circulation]

Deserts on descending limb of Hadley Cell

![Map showing distribution of annual mean insolation (W/m²)]

Salty water on descending limb of Hadley Cell
Coriolis Effect

Earth's Rotation - small apparent deflection objects in motion
Why?
- Higher rotational velocity w/ distance from axis of rotation
  - right - N. hemisphere
  - left - S. hemisphere
Deflects wind and currents

High vs. low pressure

Clockwise-rotating, falling air, high pressure cells: no rain
Counterclockwise-rotating, rising air, low pressure cells: lots of precipitation

In Northern Hemisphere

Major Wind Patterns

**Trades NE and SE**
1. 30° N/S to equator
2. Return flow of the Hadley Cell

**Westerlies**
1. 30°- 60° N/S
2. Poleward surface return flow of the Ferrel cell
   - mid-latitude storms
   - intensity reduced over continents

**Polar Easterlies**
1. 90 to 60°N/S
2. Polar highs
Land-Sea Air Flow

Water has a higher heat capacity than rock. Water can store more heat. Land cools/heats faster. This difference creates the large thermal contrasts between land and sea that shifts seasonally.
Equator-to-pole heat flow
50% by atmosphere, **50% by oceans**

Northward Flux

The ocean is density stratified by temperature and salinity

Surface vs. deep ocean circulation

http://ingrid.ldgo.columbia.edu/SOURCES/LEVITUS94/oceanviews2.html

**Surface Ocean Circulation**

Ocean is constantly moving - currents, eddies, etc.

What sets the oceans surface in motion?

**Solar energy and Earth’s Rotation**

**Primary forces** - initiate water movement
- wind stress
- density differences
- thermal expansion

**Secondary forces** - modify direction and intensity of flow
- coriolis effect
- gravity
- friction
- shape of the ocean basins
Surface Ocean Circulation
Involves about 20% of world’s ocean volume

Surface flow is **driven by the winds.**
Surface ocean currents generally follow trends in the wind field.

**Surface Ocean Circulation**

**In Northern Hemisphere:**
Strong, warm, northward flowing current on east coasts of continents.
Broad cool, southward flowing currents on west coast of continents.
If the winds fail, circulation does too.

**Sea Surface Temperatures and Currents**
Dynamic Topography

Ekman Spirals and Upwelling

Deep Ocean Circulation

Involves about 80% of world’s ocean volume

Thermohaline - subsurface (1-5 km) currents generated by temperature and salinity density gradients

- Polar regions - waters cool and sink
- current velocities - 2 m/day to 10’s m/day
Deep-water formation sites

1. North Atlantic - deep and intermediate waters
2. Antarctic - deep and intermediate waters
3. North Pacific - intermediate water

North Atlantic Deep Water
- Gulf Stream (35%)
- Temperature: 2-4°C
- 2 to 4 km

Antarctic Bottom Water
- Fills most of the deep ocean below 3.5 km
- 34.6‰, <2°C, most dense

Antarctic Intermediate Water (AAIW)
- 1.0 - 1.5 km
- Low salinity 34.2‰
- 2 to 4°C

Temperature, Salinity, and Density

How does sea-ice formation increase the density of seawater?

1. Cooling - as ice forms - latent heat lost to atmosphere
   - Water cools, atmosphere warms
2. Salt exclusion - elevating salinity of surface water

Convection - less dense waters rise in fingers & replace sinking waters
Drives deep water circulation