4 THE PHYSICAL SYSTEMS OF PLANET EARTH

The Engine of Life

PowerPoint® Lecture prepared by Gary A. Beluzo

STUDENT LEARNING OUTCOMES

After reading this chapter, students will be able to

- Explain how a convection cell can be used to explain patterns of circulation in the atmosphere, ocean, and Earth's surface.
- Explain how gradients in incoming solar energy generate predictable patterns of temperature, precipitation, and winds.
- Describe the factors that cause ocean water to circulate horizontally and vertically.
- Describe how the energy from Earth's interior causes matter to flow from the interior to the surface and back again.
- Compare and contrast changes in atmospheric and oceanic circulation that are associated with El Nino events.

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Small Changes, Big Effects

- ***The Day After Tomorrow*** movie
- Planet Earth changes within weeks
- How did Hollywood make the film "**believable**"?
- Based on the shift in the flow of seawater between the ocean surface and depths. Stops the Gulf Stream
- Without the Gulf Stream bringing warm water northward, the eastern U.S. would cool in **decades**
- **The Butterfly Effect (nonlinearity and distance effects)**

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Energy from the Sun

- **$E=mc^2$** describes the Sun's thermal nuclear fusion that converts hydrogen atoms to helium and energy
- The photosphere (outer layers of sun) radiates energy to Earth at about 6,400 degrees ºC (11,552 ºF)
- The amount that reaches the Earth's atmosphere is 1.97 calories/cm^2 (**12.7 kcal/$inch^2$**)
- Radiation
- Scatter
- Reflection
- Absorption
- Albedo

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Incoming Solar Energy

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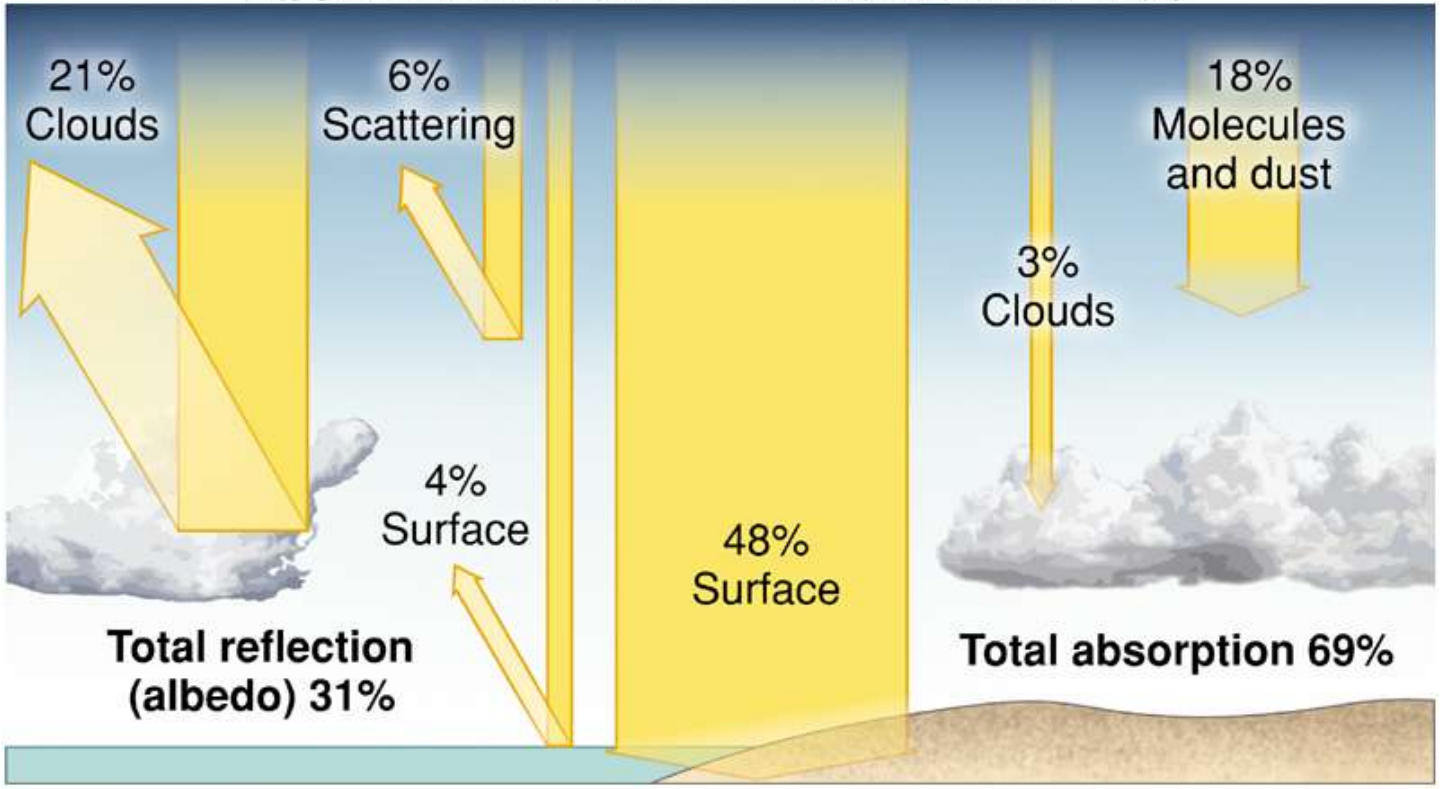

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Work Done by Solar Energy

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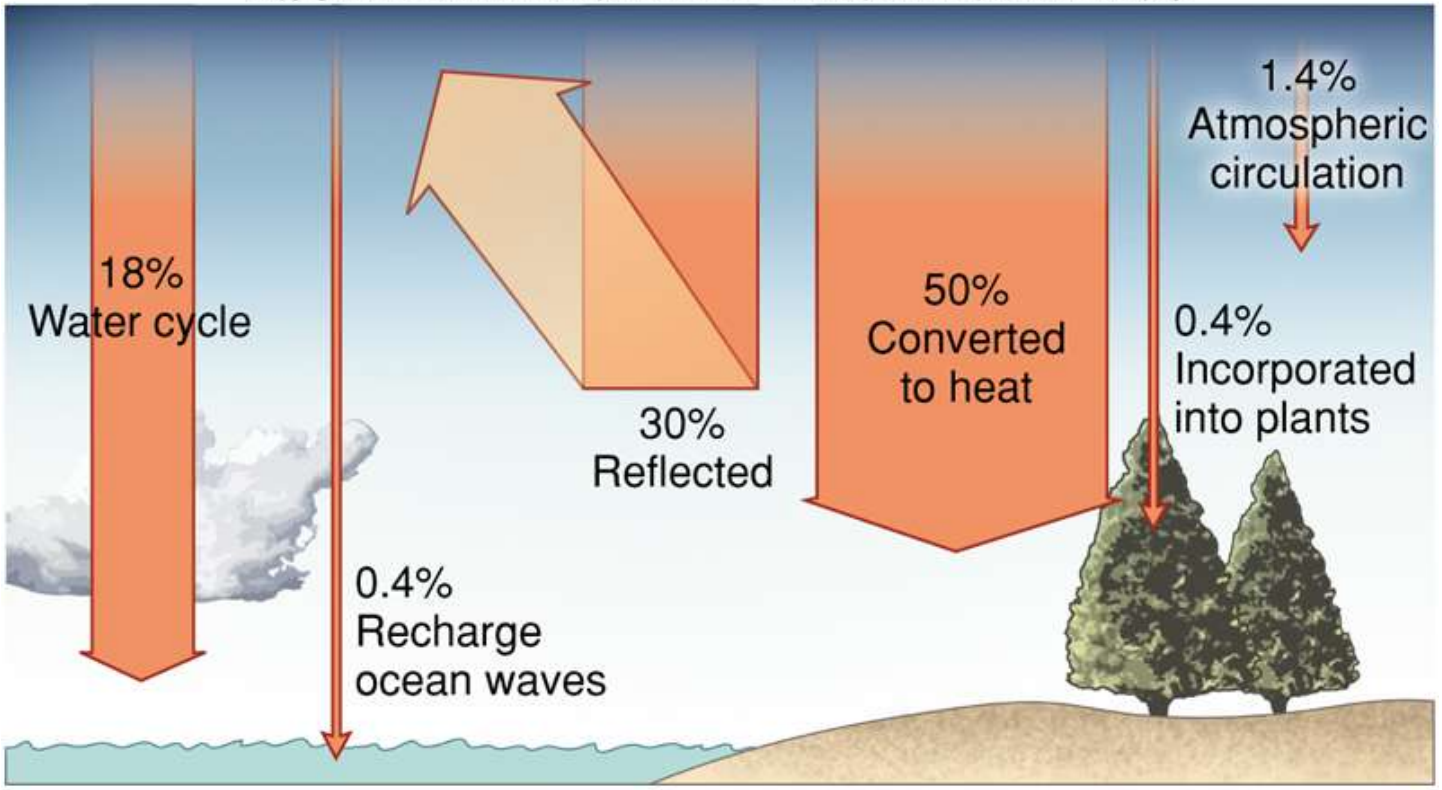

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The Earth's Interior

- Some heat left over from formation
- Most associated with radioactive decay of elements
- Total heat flow from Earth interior is **2×10^{17} kcal**. How much per square inch?
- This total is greater than the global use of coal, oil, natural gas, and electricity generated from nuclear and hydropower plants but- **<1% of energy from the Sun.**
- Also, the total work done at the surface by the Sun only affects the upper few meters of Earth's surface

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A Simple Model of Physical System

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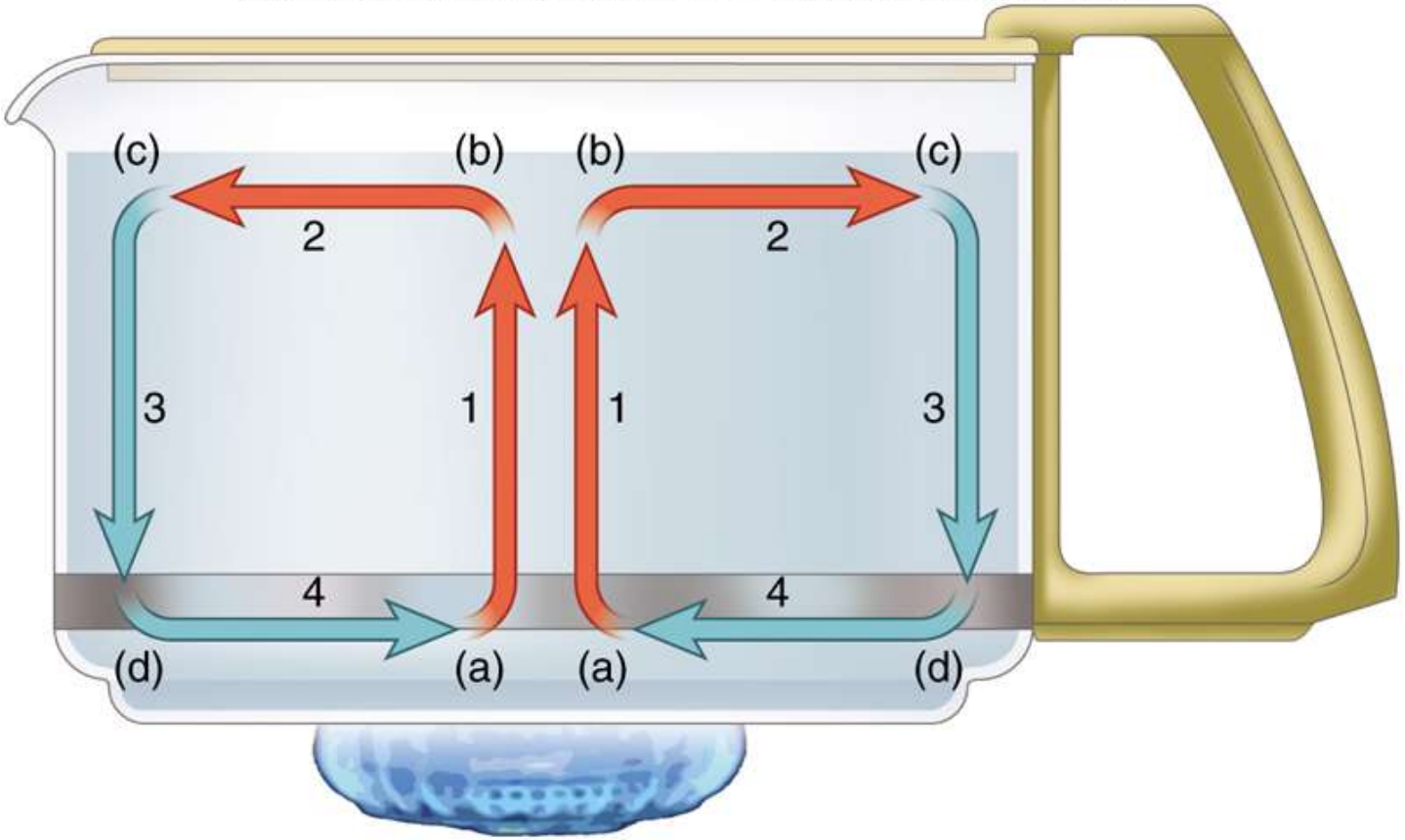

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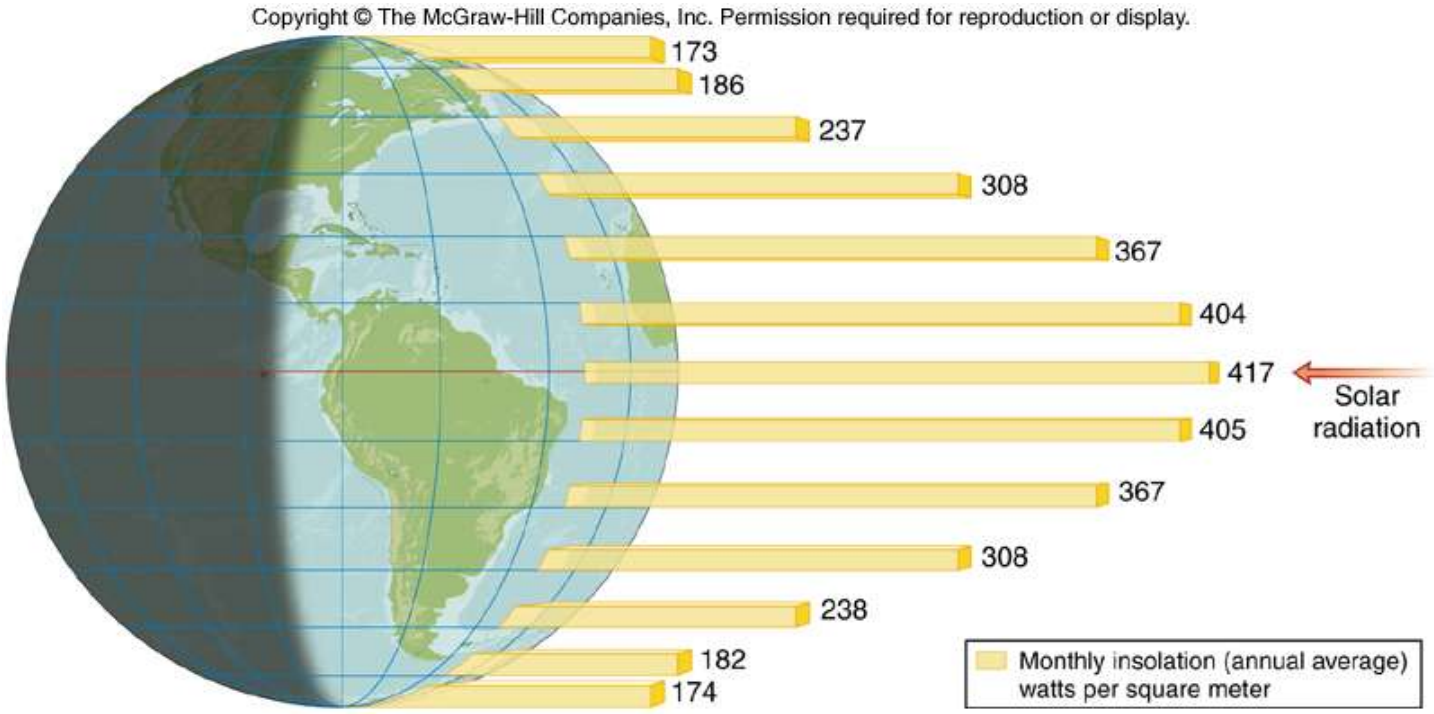
Differential Solar Radiation



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Radiation Balance

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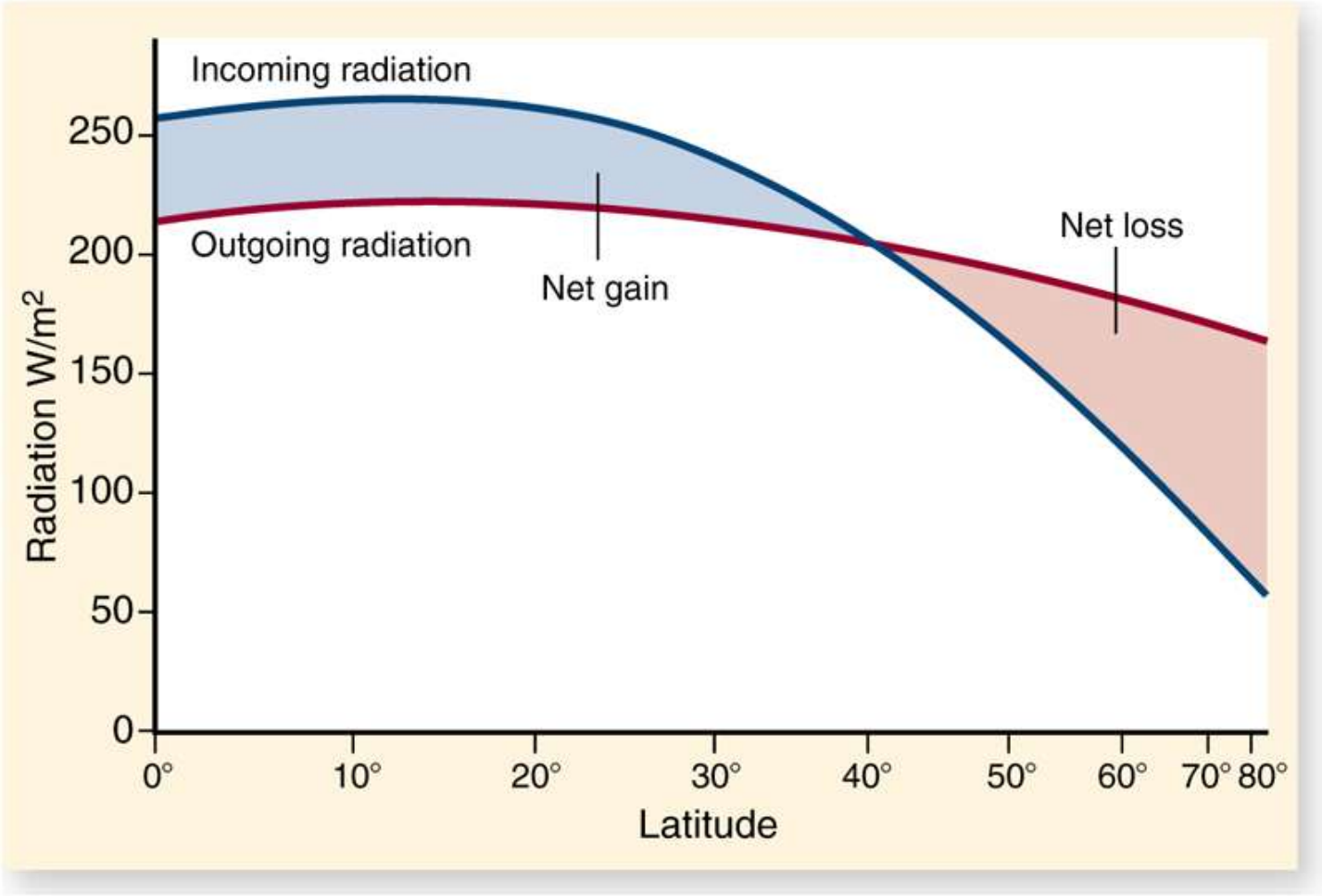

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Global Heat Transport

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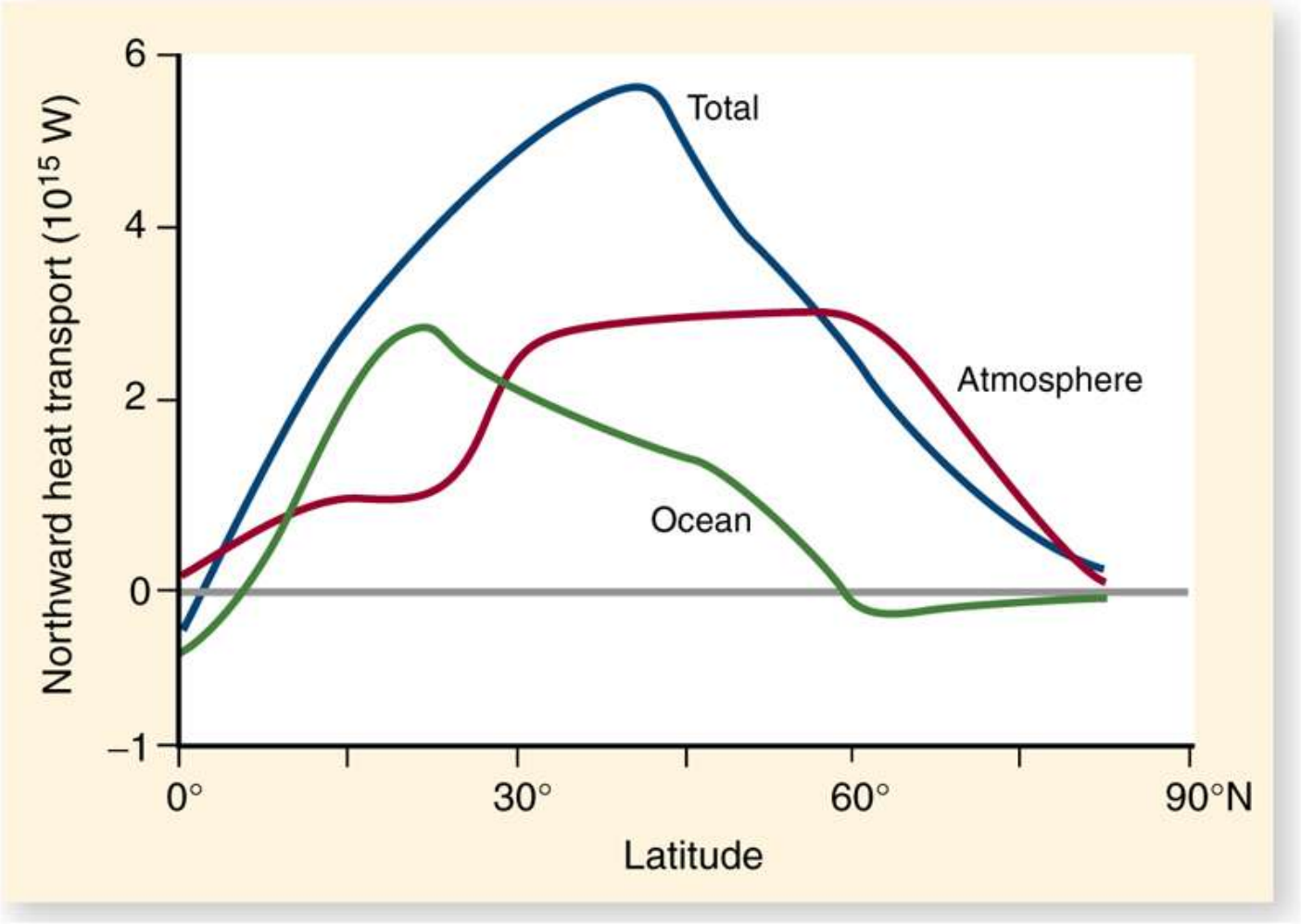

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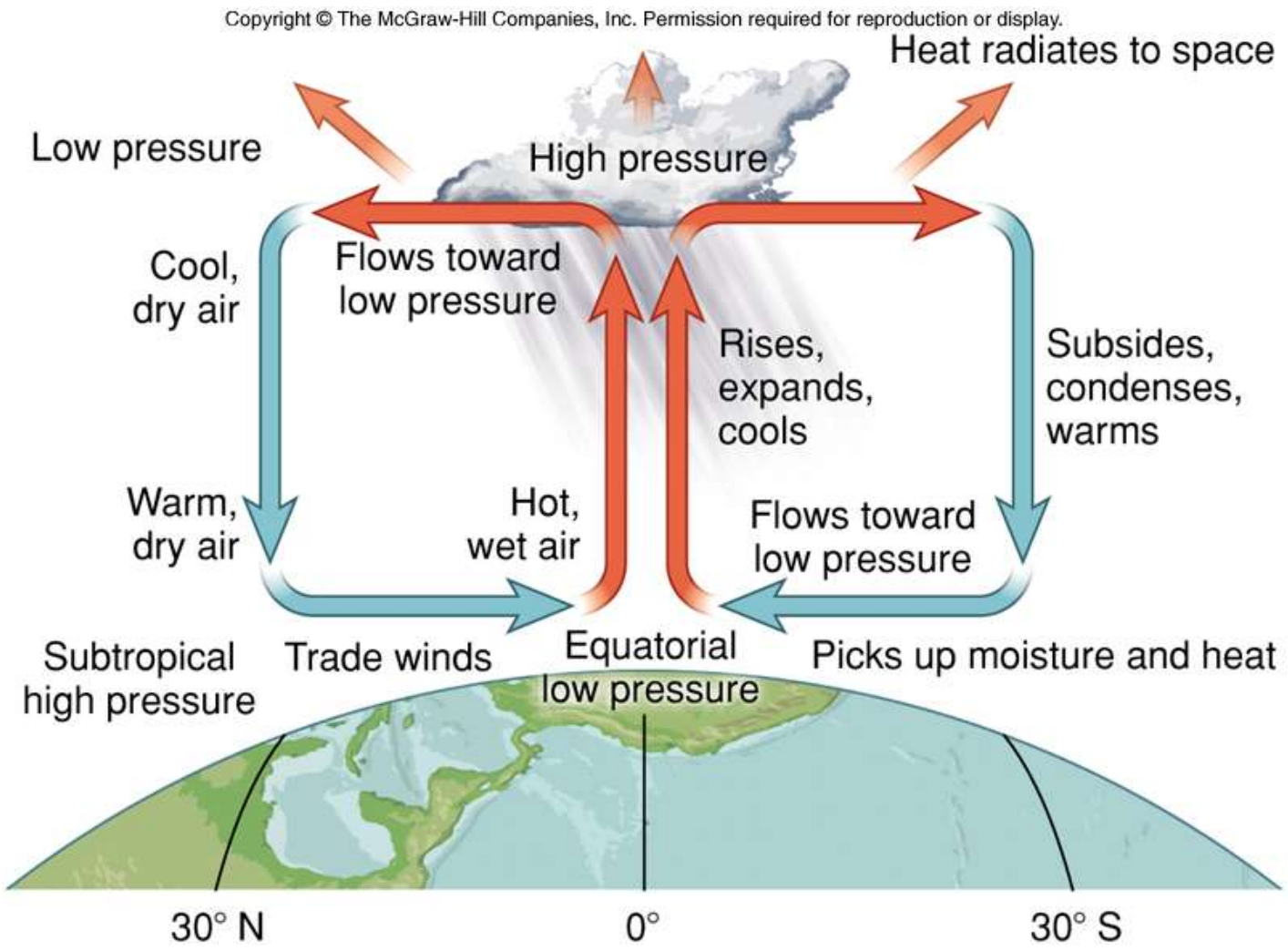
Atmospheric Convection Cell



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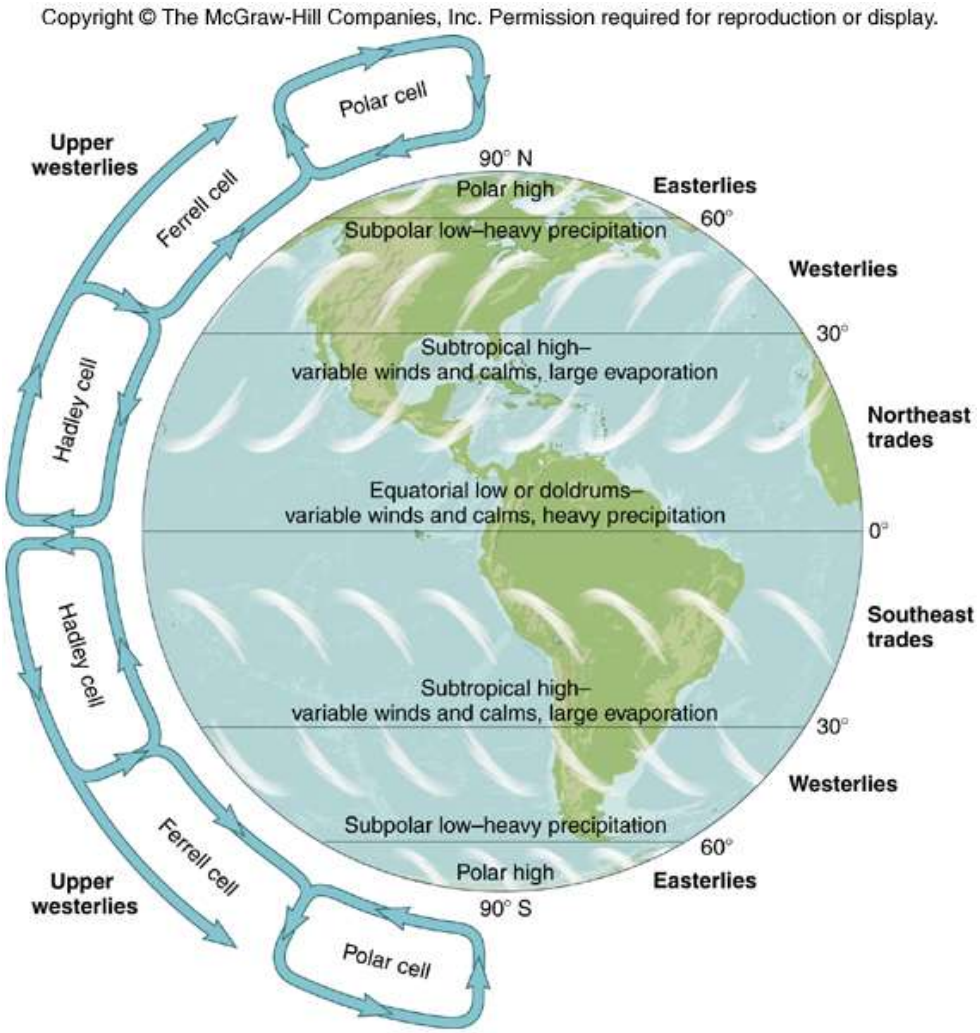
Atmospheric Circulation



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Coriolis Effect

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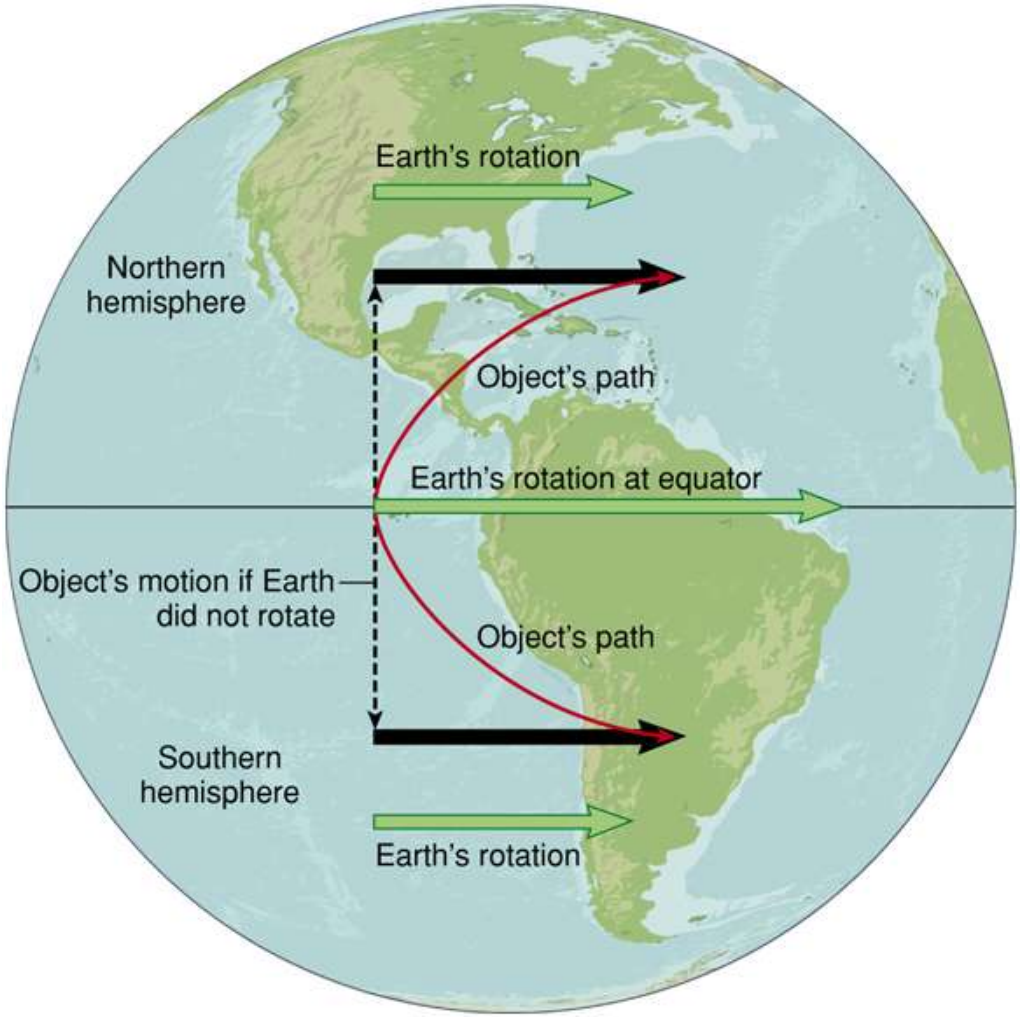

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Global Patterns of Precipitation

- As air moves through a circulation cell the ability to hold water changes
- Air picks up moisture as it moves along the ground
- Water condenses as it rises, this generates large amounts of rain/snow near equator and the polar front
- Air absorbs very little water as it moves parallel to Earth's surface along upper arm of cell
- As air descends, its temperature and pressure rises, holding less water
- World's deserts are found at about 30 degrees North and South.

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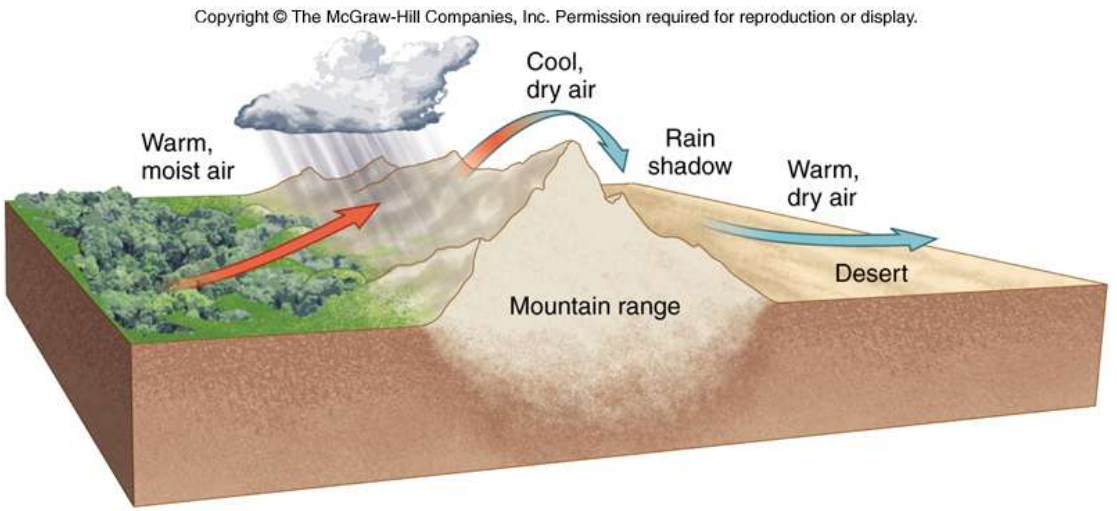
Orographic Rainfall

- Other deserts are formed downwind from large mountain ranges.
- As air rises up the windward side of the mountain precipitation increases
- As air descends on the leeward side, there is little rain
- Mojave Desert (leeward side of San Gabriel and San Bernardino)



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Environmental Services from Atmospheric Circulation

- Air movements produce clean air and drinkable water
- And ***predictable*** climate is important
  - No circulation?
  - Advection (motion of individual molecules)?
  - Complete random flow of air?
  - But the convection cell- predictable patterns allow for plants, animals, and human societies to adapt to the range of conditions there

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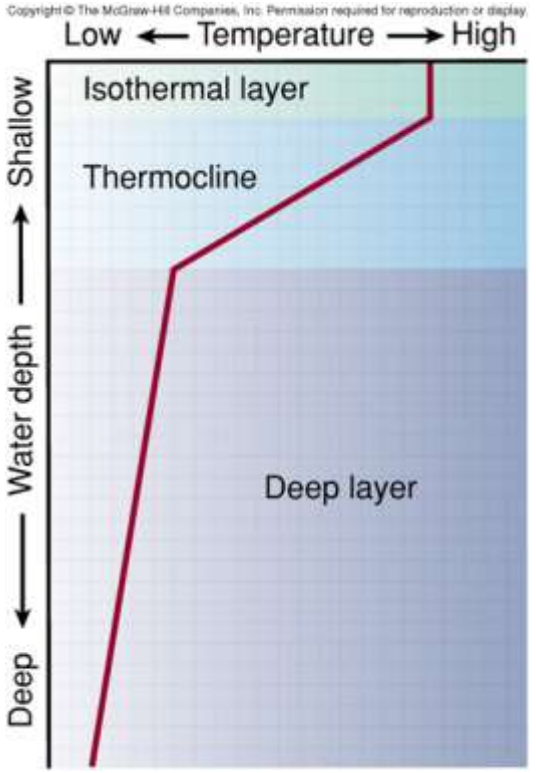
Physical Properties of Water

- Specific Heat (water is 1.0, rock is 0.2)
- Evaporation releases large amount of heat and thawing absorbs a large amount of heat
- Ocean heats up and cools down much slower than land
- Temperature Profile
  - Water is most dense at 4 degrees C
  - Thermocline (steep temperature gradient)
  - Barrier to mixing (layers differ in chemistry)



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Patterns of Oceanic Circulation

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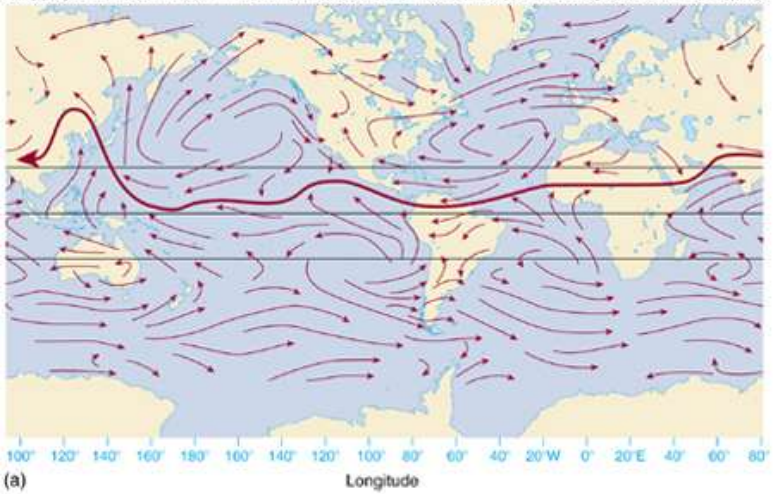

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Ekman Transport

- Atmosphere and ocean series of layers with air the least dense and ocean the most dense.
- Some of air movement transferred to the water
- At each transfer down, the movement slows and Coriolis bends movement to the right.
- Total effect is that ocean current is 90 degrees to right of the surface winds in the northern hemisphere.

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Ocean Currents at the Surface

- At equator, surface water tend to move west
- North of equator, currents have a northward component
- Moves water away from equator and is critical to El Nino events
- Surface waters move west until they reach eastern shore of continent and water deflected north, generates the Gulf Stream.
- Relatively mild climate of mid-Atlantic states results from the Gulf Stream.
- Between 30-60 degrees surface water flow east until they reach western shore of continent. Again deflected North.

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Thermohaline Circulation

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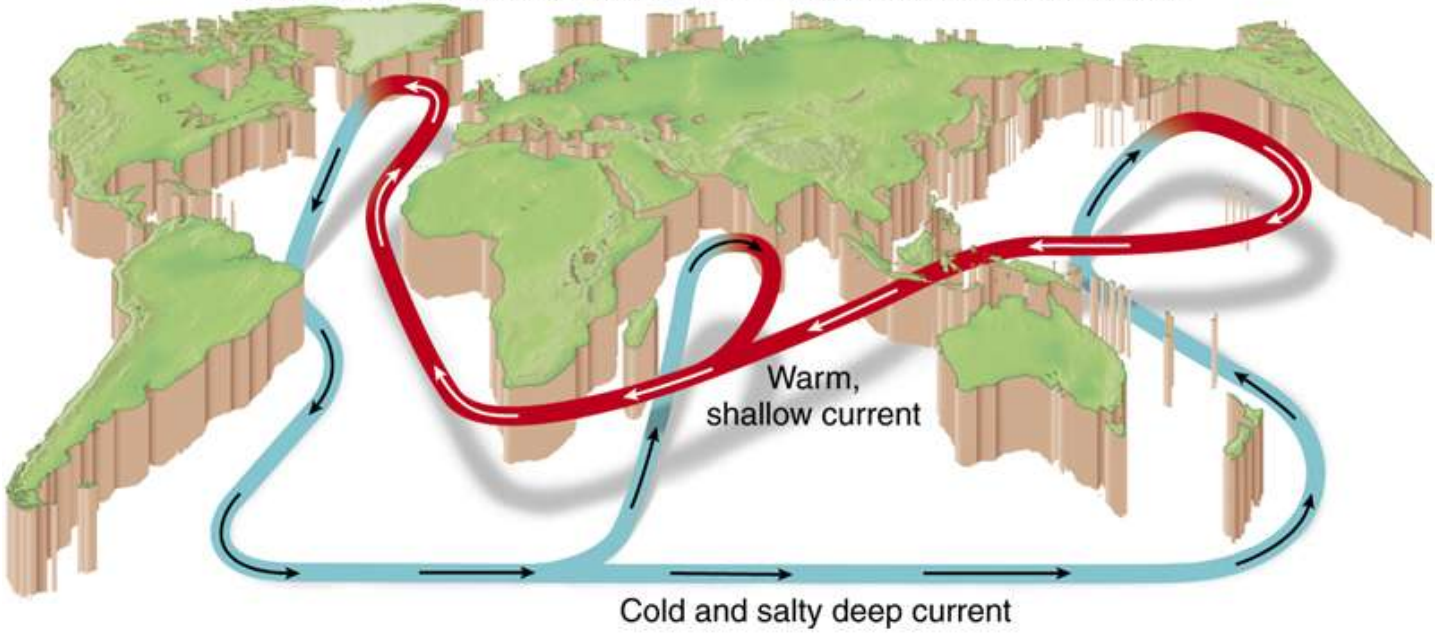

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El Nino: Environmental Services of Oceanic Circulation

- Oceanic circulation is important determinate of climate
- Redistributes materials critical to life.
- El Nino occurs every 3-7 years off the coast of Peru
- Most years, SE trade winds blow from subtropical high off coast of Peru to Indonesian equatorial low, normally just north of Australia
- During these normal years the trade winds blow across the warm Pacific and rain supports tropical rain forests in Indonesia, wheat production in Australia, monsoon rains support rice in India.
- Upwelling off coast of Peru for anchovy fisheries.
- When trade winds blow strongly this termed "**La Nina**".

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El Nino

- During an **El Nino** event, positive feedback loop reinforces an initial disturbance so the zone of high pressure off Peru becomes progressively weaker
- As subtropical high becomes weaker, the weaker gradient slows the trade winds.
- Less moisture in the western Pacific so monsoons fail in India, Australia has a drought.
- Rainfall increases over portions of U.S.
- Upwelling slows, anchovy industry suffers
- Disruption in environmental services; biological and human systems affected throughout the world

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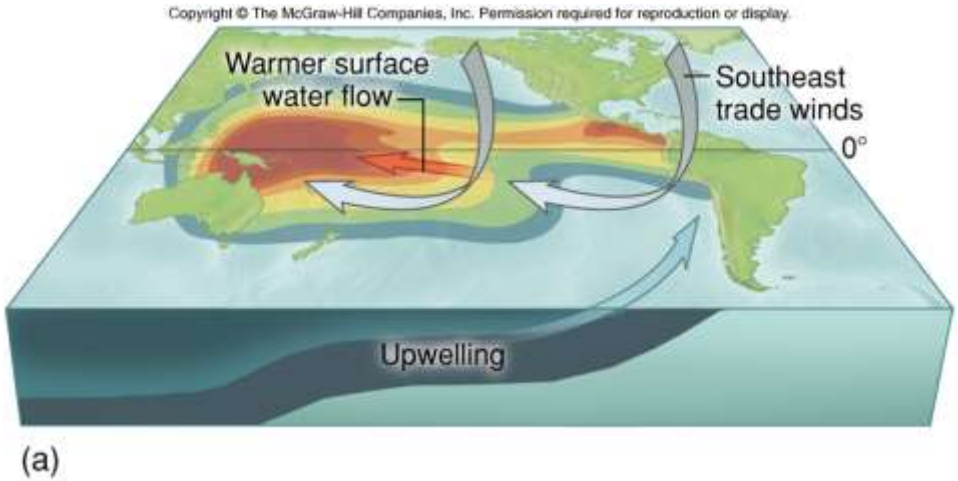
El Nino Cycle



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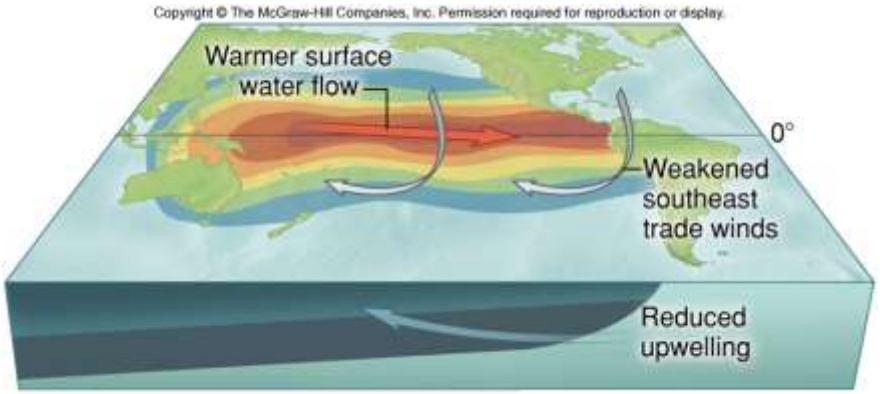

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The Southern Oscillation Index

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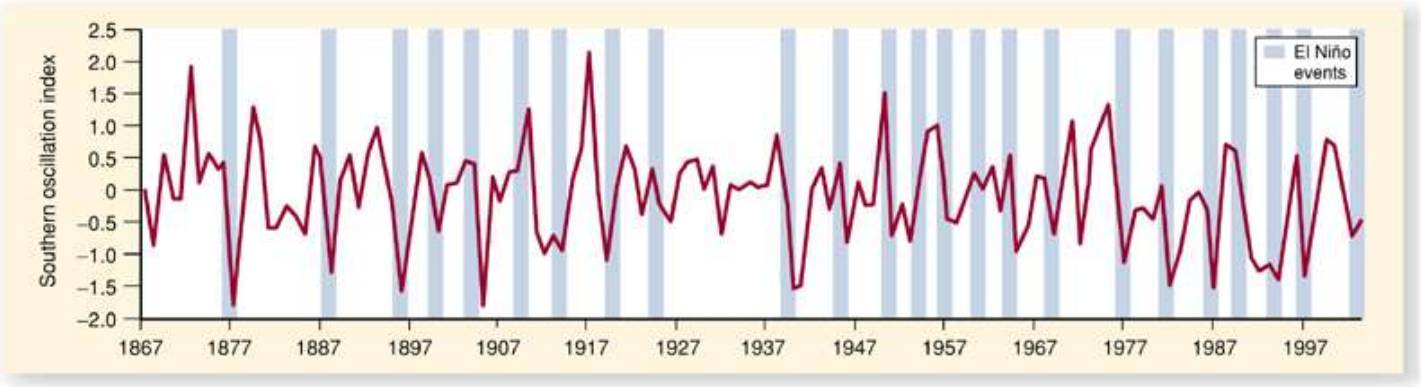

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Plate Tectonics

- In **1596**, Dutch map maker, Abraham Ortelius, wrote that the eastern coast of South America “fits into” the western coast of Africa
- In 1912, formalized into the **Theory of Continental Drift** by Alfred Wegener
- 1960s, better maps of the ocean floor and earthquake epicenters indicated the crust was made of **plates**.

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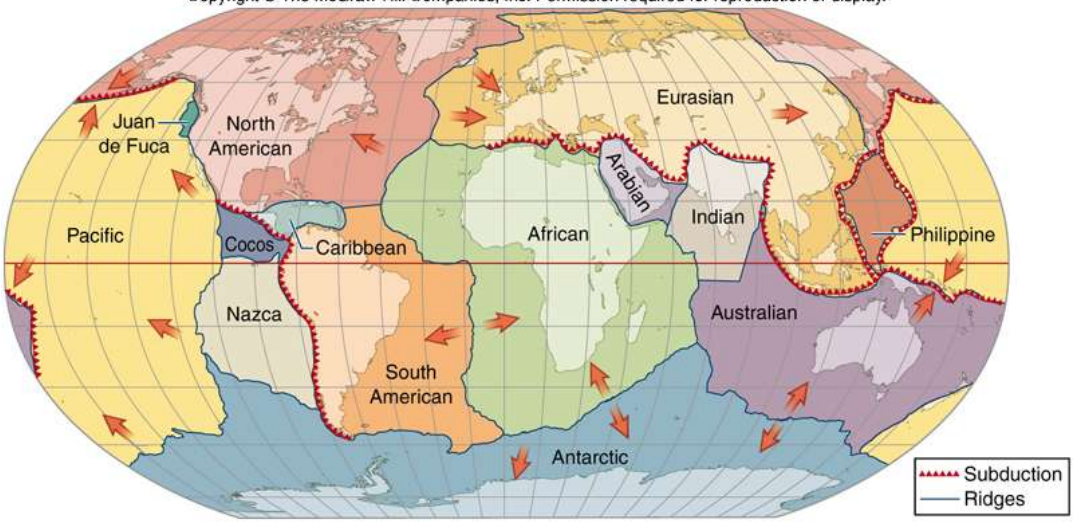

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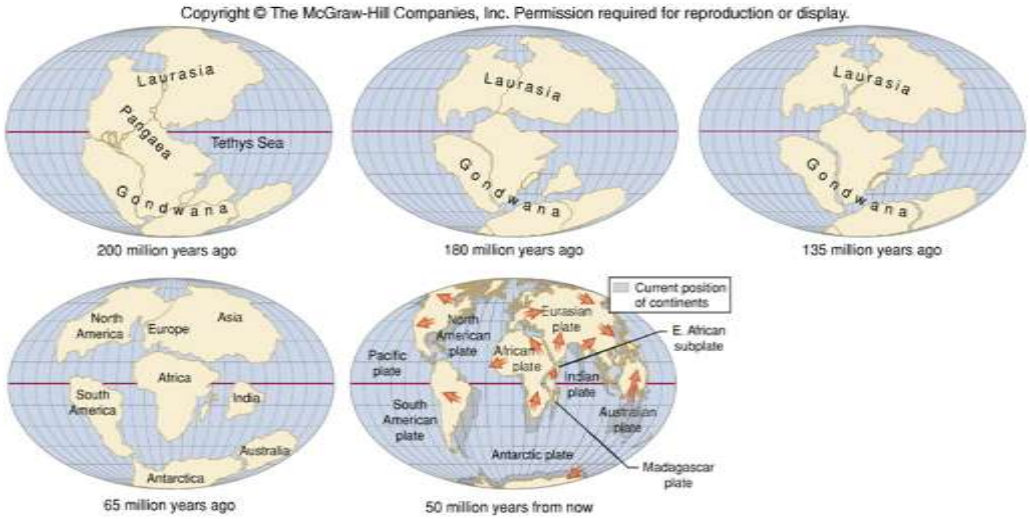
Plate Tectonics

- Crust moves about 2 centimeters/year in North Atlantic
- Amount of new crust formed at ridges balanced by amount of crust destroyed



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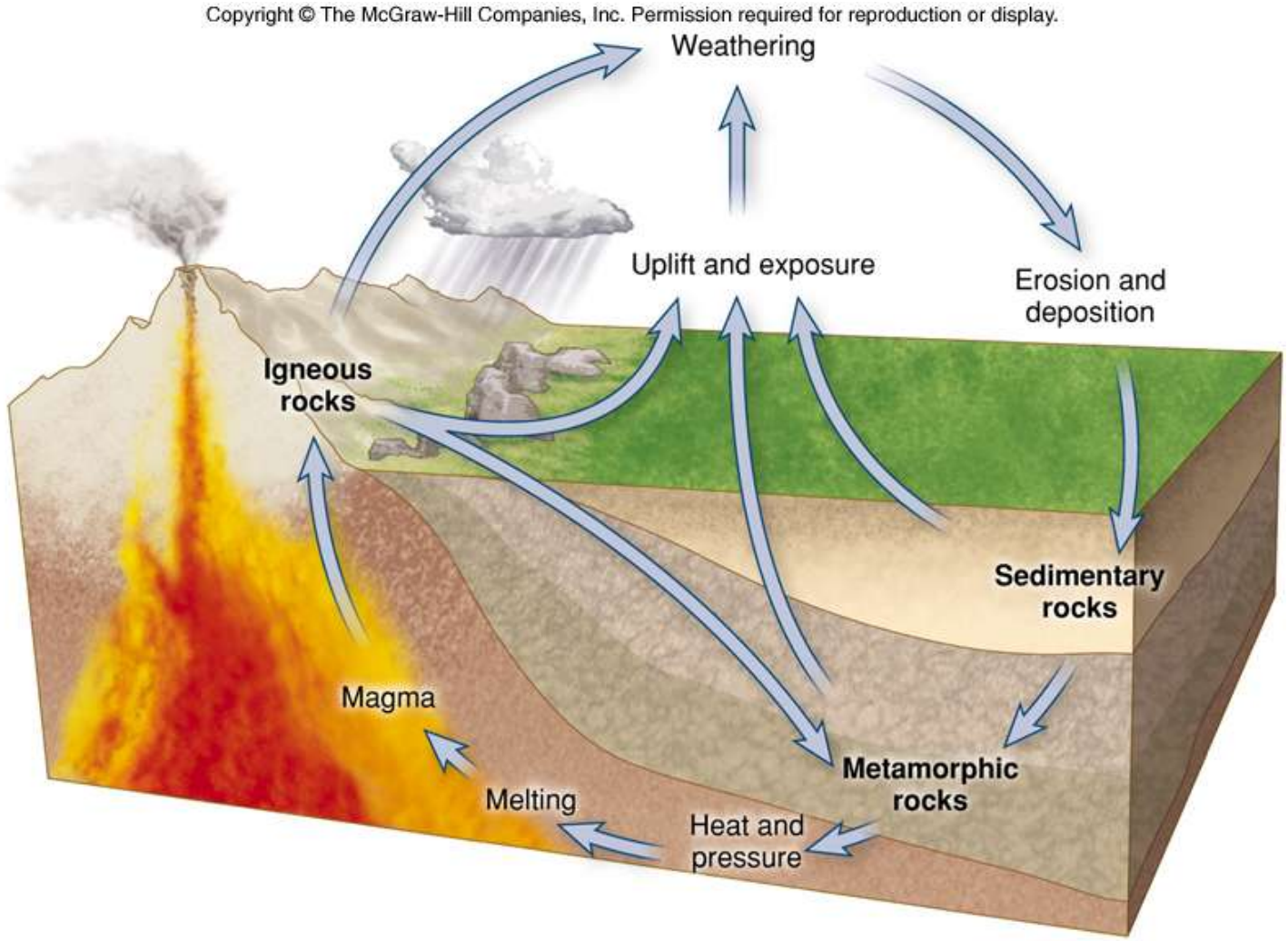
The Rock Cycle



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Rocks

- Igneous rocks
  - Weathering
  - Sediment
  - Erosion
- Sedimentary Rocks
  - Consolidation
  - Lithification
- Metamorphic
  - Pressure and/or temperature

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Natural Resources and Environmental Services

- Geothermal heating
- Biogeography and Biological Diversity
- Chemistry of the Ocean
- Residence time of Ocean is 8 million years
- Mineral Formation
- Fossil Fuels

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