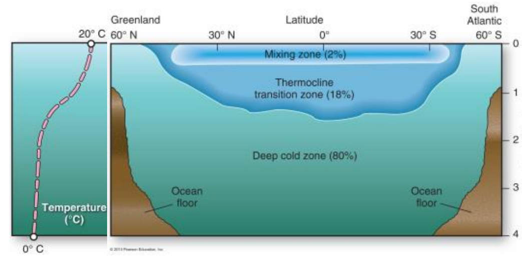
Ocean Water Circulation

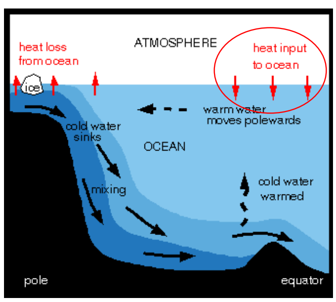
- Ocean circulation is driven by contrasts in temperature, composition, and density of ocean waters
- Circulation involves both shallow and deep water currents
- Actual pathways influenced by:
  - Earth’s spin
  - Positions of continents



Three layers in the ocean:
- Surface mixing zone varies in temperature with latitude and seasons
- The thermocline transition zone where temperature dramatically decreases with depth
- Deep cold (near freezing) zone relatively uniform in temperature

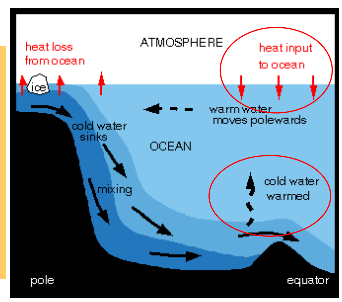
Formation of Deep Water

- Near the equator, heat input into the ocean warms deeper, cold water



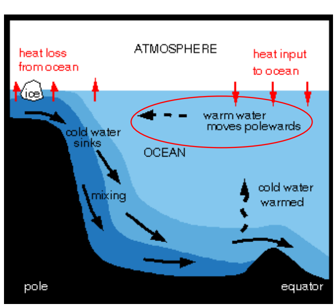
Formation of Deep Water

- Near the equator, heat input into the ocean warms deeper, cold water
- Warmed deep water becomes less dense and rises towards the surface to join the warm shallow current



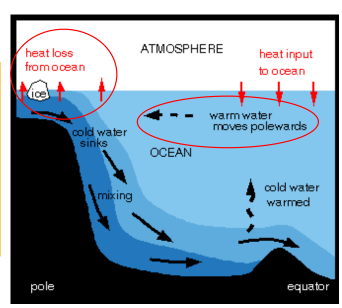
Formation of Deep Water

- Warm, shallow current flows northward towards the pole



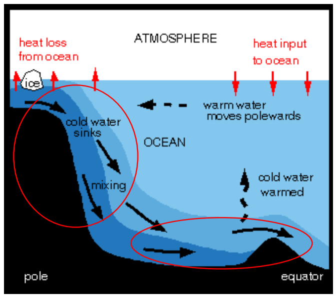
Formation of Deep Water

- Warm, shallow current flows northward towards the pole
- Further north, warm currents cool due to heat loss from the ocean

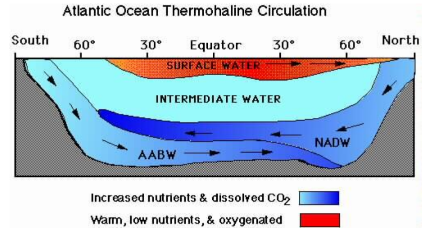


Formation of Deep Water

- Ocean water near poles sinks when it's density exceeds that of surrounding water
- Higher density caused by:
  - Colder temperature
  - Higher salinity
- Cold bottom water flows southward

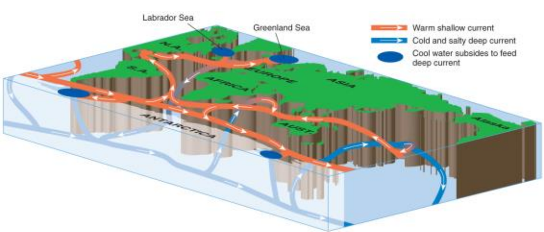


Deep Ocean Water



- Migration of deep ocean water is slow (averages 5 km or 3 miles a day)
- Two principle deep water flows:
  - North Atlantic Deep Water
  - Antarctic Bottom Water (deepest)

Deep-Ocean Thermohaline Circulation



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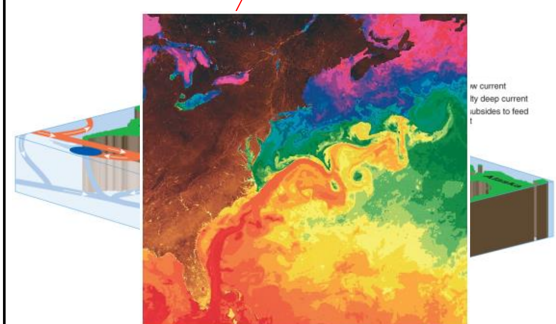
Thermohaline circulation driven by differences in temperature and salinity

Warm, Shallow Gulf Stream Flows Towards North Atlantic and Cools



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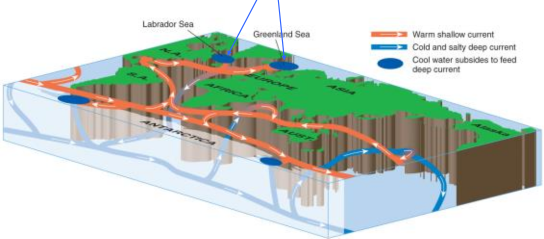
Cool Water Subsides in Labrador and Greenland Seas To Form North Atlantic Deep Water



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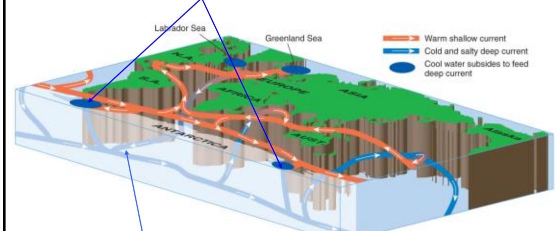
Cold Surface Water Subsides Off Antarctica To Form Antarctic Bottom Water



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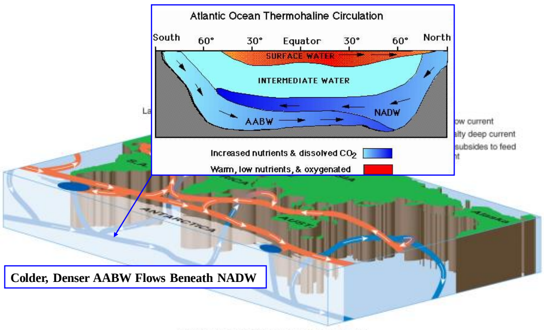
North Atlantic Deep Water Reaches Antarctica



Colder, Denser AABW Flows Beneath NADW

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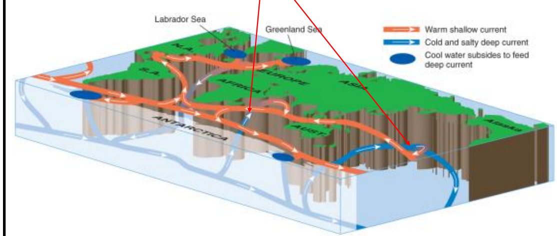
Farther North, Deep Bottom Currents Warm and Rise Towards Surface To Join Warm, Shallow Currents That Flow To The North Atlantic



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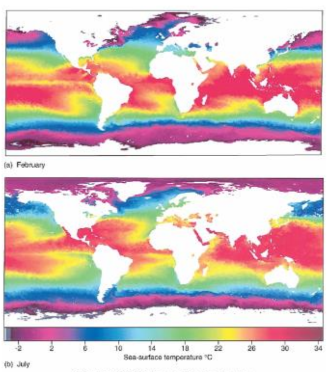
Surface Waters

- The surface ocean layer is in direct contact with the atmosphere and warmed by Sun's energy
- Temperatures vary with latitude and seasons
- Surface layer is moved horizontally by wind and wave action



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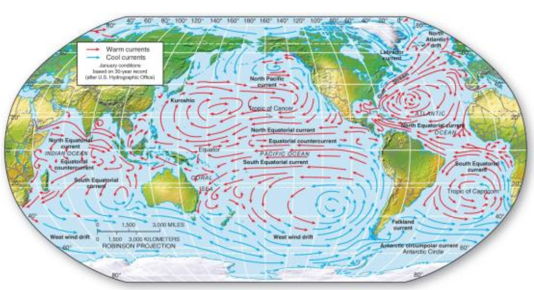
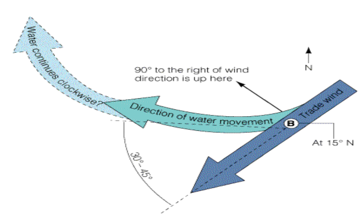
Ocean Currents

- Ocean currents are relatively narrow channels of swift-moving surface water:
  - Velocities typically 10 km/day but locally may attain 160 km/day
- Ocean currents move in definite and predictable directions
- Distribute heat and nutrients in the oceans



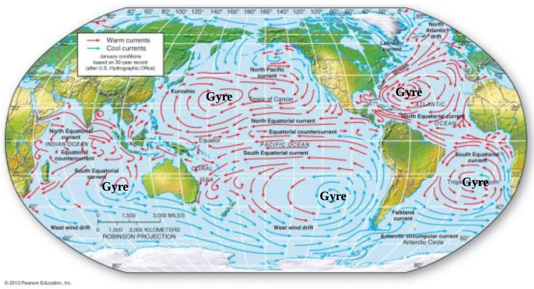
- Surface ocean currents are driven by the winds
- The direction of currents is influenced by the Coriolis Effect
- Land masses redirect currents

Gyres

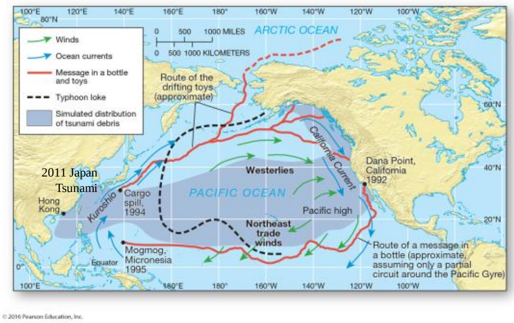


- Surface ocean currents are continually deflected towards the right in the northern Hemisphere (to the left in southern hemisphere) by the Coriolis Force
- Surface ocean currents flow in a clockwise loop in the northern hemisphere (counterclockwise in southern hemisphere) to form gyres
  - Examples: North Atlantic and Pacific gyres

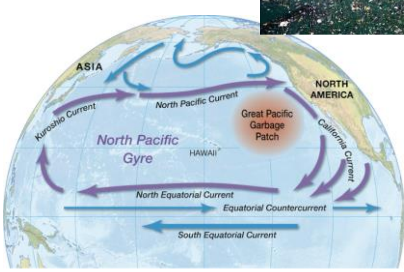
Gyres Associated With Subtropical Highs



Pacific Gyre



Great Pacific Garbage Patch



Ocean Circulation

Ekman Spiral

Multiyear Oscillations in Global Circulation

- Several system fluctuations occur in multiyear or shorter periods due to changes in the strength and/or location of primary high and low pressures:
  - North Atlantic Oscillation: Pressure differences between the Icelandic low and Azores high alternate in strength
  - Pacific Decadal Oscillation: Involves temperature and pressure fluctuations between the northern and tropical Pacific Ocean over durations of 20-30 years
  - Southern Oscillation: Originates in the tropical Pacific and accompanies El Niño

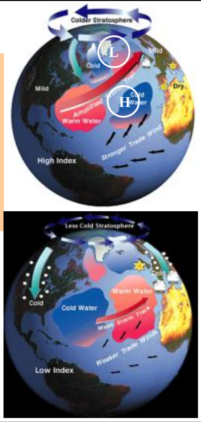
North Atlantic Oscillation

Positive Phase: Colder stratosphere (polar vortex): Strong low pressure over Iceland and strong high pressure over Azores:

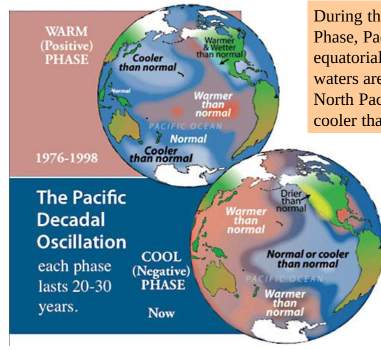
- Strong polar jet stream confines cold polar air to northern Europe and the Arctic.
- Strong storm track takes warm air on more northerly path towards Scandinavia.
- Mild weather conditions prevail in the U.S. and throughout Europe

Negative Phase: Less cold stratosphere: Both Icelandic Low and Azores High weaken:

- Weakened polar jet stream undulates, allowing cold polar air to spill southward.
- Winters in U.S. and Europe are much colder.
- Weak storm track takes warm air on a more southerly course towards the Mediterranean.



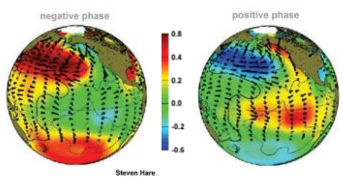
Pacific Decadal Oscillation

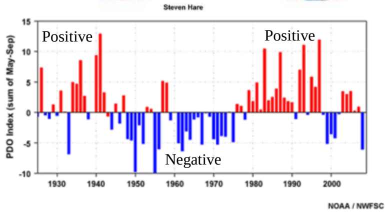


During the Positive Phase, Pacific equatorial surface waters are warmer and North Pacific waters cooler than normal

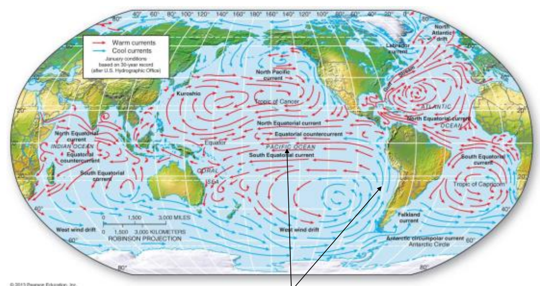
During the Negative Phase, Pacific equatorial surface waters are cooler and North Pacific waters warmer than normal

Pacific Decadal Oscillation





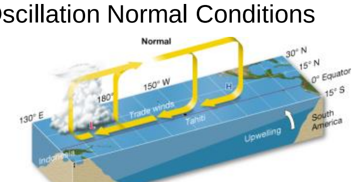
El Niño – Southern Oscillation



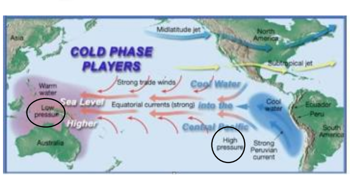
Peruvian and South Equatorial Currents are part of CCW circulation of winds and ocean currents around a subtropical high-pressure cell in the southern Pacific

Southern Oscillation Normal Conditions

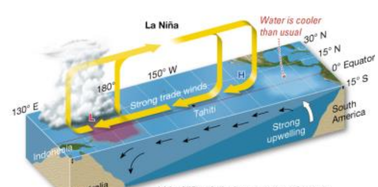
- Low pressure in western Pacific, high pressure in eastern Pacific
- Rainfall in Australia and SE Asia
- Southeasterly trade winds drive surface ocean water westward along equatorial Pacific
- Upwelling along S.A. coast brings deep-water nutrients to shallower depths
- Fishing is good



(a) Normal wind, air pressure, and ocean conditions.



La Niña

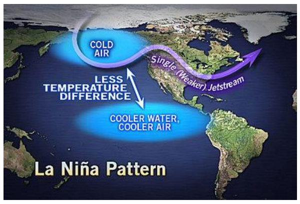


(c) La Niña wind, air pressure, and ocean conditions.

Results when normal conditions along equatorial Pacific intensify:

- Pacific trade winds are stronger than usual, pushing warm surface water farther west
- Results in strong upwelling of cold water along eastern Pacific coastlines (e.g. west coast of South America)
- Equatorial waters become cooler than normal

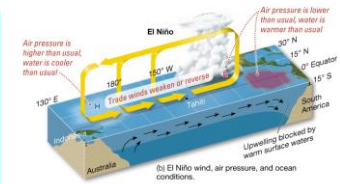
Climatic Effects of La Niña in North America



Southern Oscillation And El Niño

Region of high atmospheric pressure see-saws from one side of the Pacific to the other:

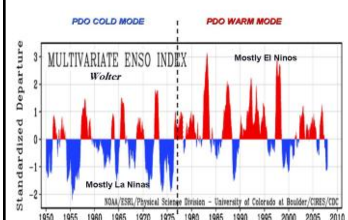
- When high pressure is in the western Pacific, southeasterly trade winds diminish
- Drought in Australia and SE Asia
- Equatorial surface waters become warmer
- Equatorial current stops or flows eastward to produce El Niño
- Upwelling blocked along west coast of S.A. by warm surface water
- Fishing is poor

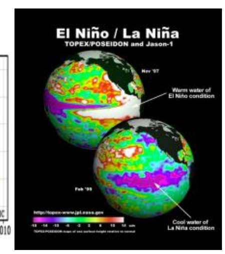


Climatic Effects Of El Niño In North America

El Niño and La Niña episodes typically last **nine to 12 months**, but some prolonged events may last for years

El Niño Southern Oscillation (ENSO) Compared With Pacific Decadal Oscillation (PDO)





PDO Cold Mode (Negative): Cooler equatorial Pacific, mostly La Niñas
PDO Warm Mode (Positive): Warmer equatorial Pacific, mostly El Niños

El Nino_La Nina