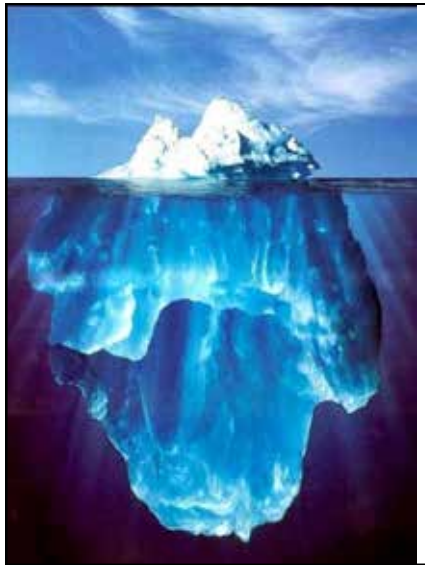
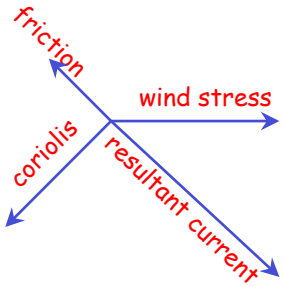
The Oceans

Wind-Driven Gyre Circulations



Icebergs

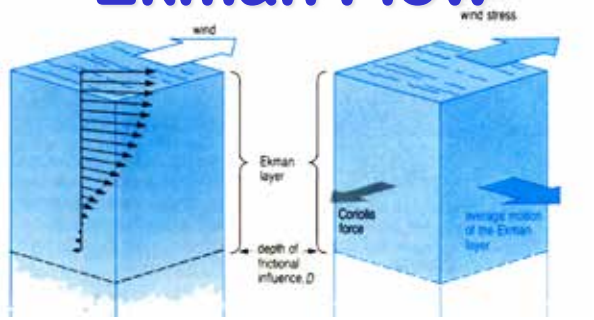
Surface Balance of Forces



- Wind stress accelerates surface water
- Friction couples surface to underlying water
- Friction always acts exactly opposite current motion
- Coriolis acceleration is always perpendicular to current motion

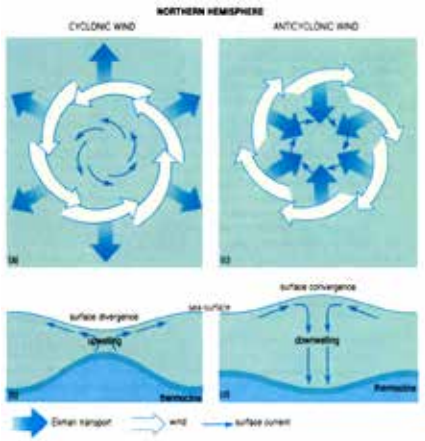
RESULT: Surface current directed about 45° (right) of wind in Northern Hemisphere

Ekman Flow



- Combined effects of Coriolis and friction on "stack" of thin layers
- Each layer moves more slowly and further right than layer above
- Average motion is 90° *to the right* of wind (in NH)

Ekman Pumping



- Ekman flow in NH is 90° to the right of the wind stress
- Cyclonic wind forces divergence in water, and upwelling
- Anticyclonic wind forces convergence and downwelling

Idealized Gyre

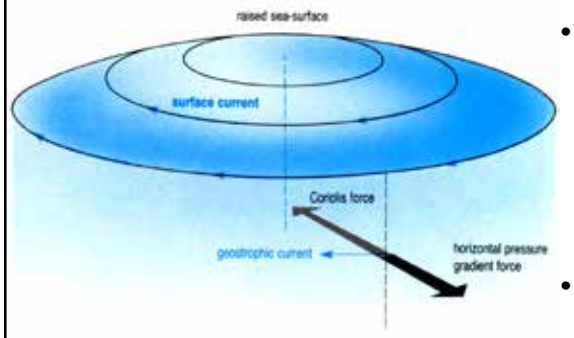


Figure 3.24 The generation of geostrophic current flow in a gyre driven by anticyclonic winds in the Northern Hemisphere. This current is driven by the wind only indirectly and persists below the wind driven (Ekman) layer

- Convergence of Ekman flow raises sea surface
- Rotating "dome" results

Asymmetric Gyre

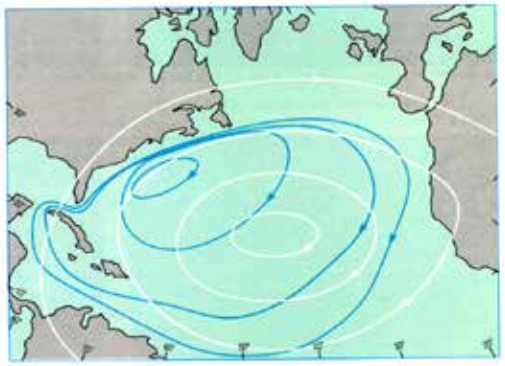


Figure 4.11 Schematic illustration of the asymmetrical North Atlantic gyre (blue) and the more or less symmetrical wind field which overlies it

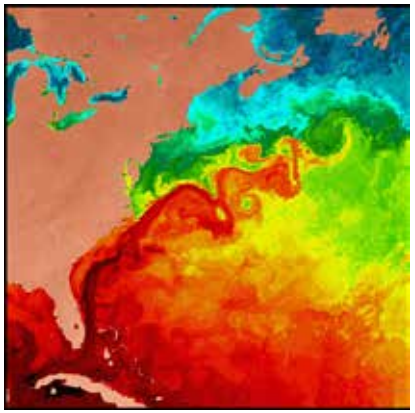
Real gyres aren't symmetrical!

Boundary currents are strong in west, weak in east

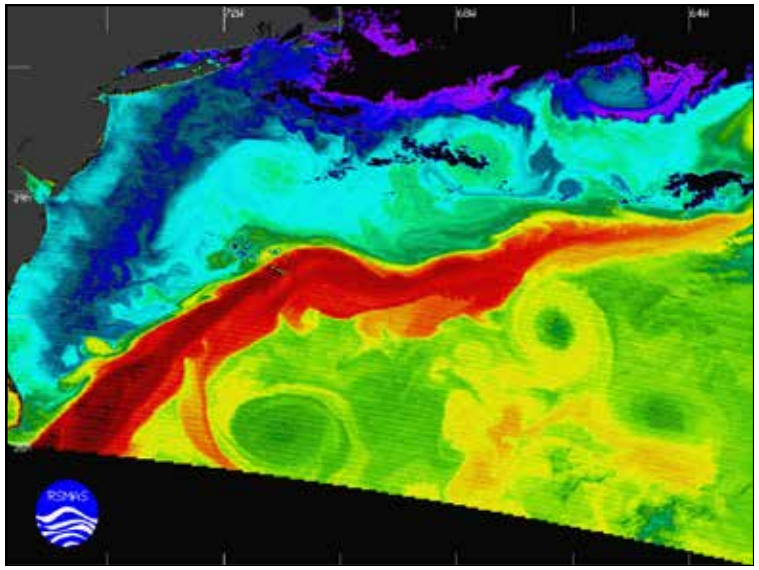
Is there a Gulf Stream?

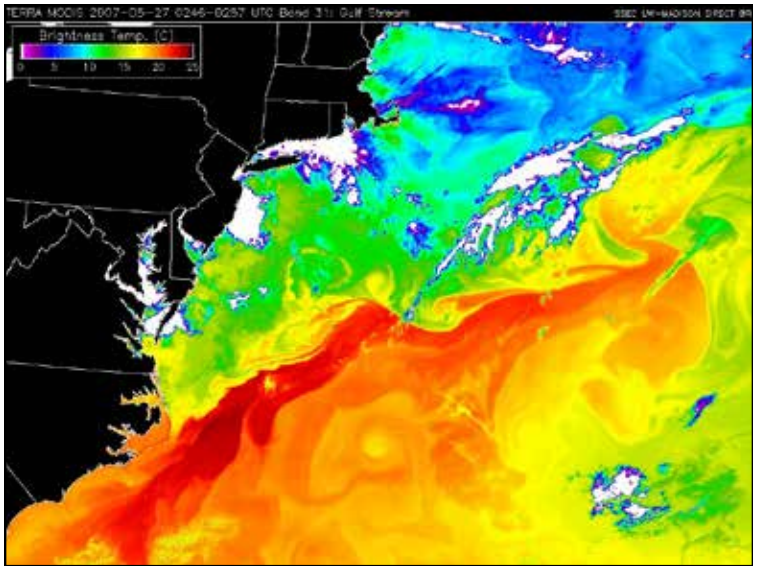
Trajectories of derelict (drifting) ships (19th century)

Sea-Surface Temperature from Space



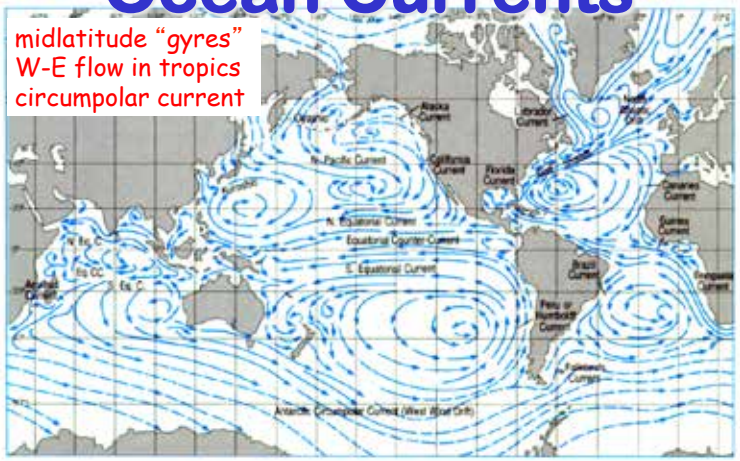
- Gulf Stream flows along the boundary of warm and cold water
- Maximum current is about 4 "knots" (~ mph)
- Note eddies and "rings" in Gulf Stream





Ocean Currents

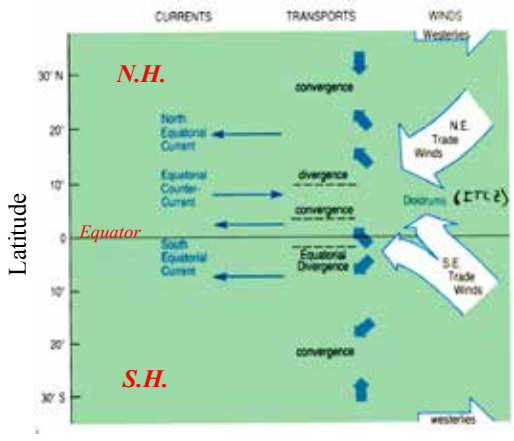
midlatitude "gyres"
W-E flow in tropics
circumpolar current



How are these known? Effects on poleward energy transport?

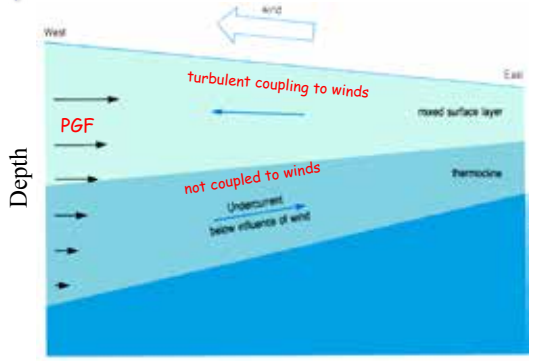
Tropical Oceans and El Nino

Tropical Winds and Currents



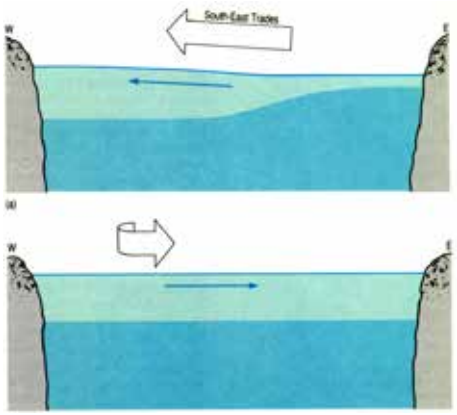
- Atmospheric convergence produces ocean divergence
- Vertical motions associated with divergent currents control SST

Equatorial Cross-Section

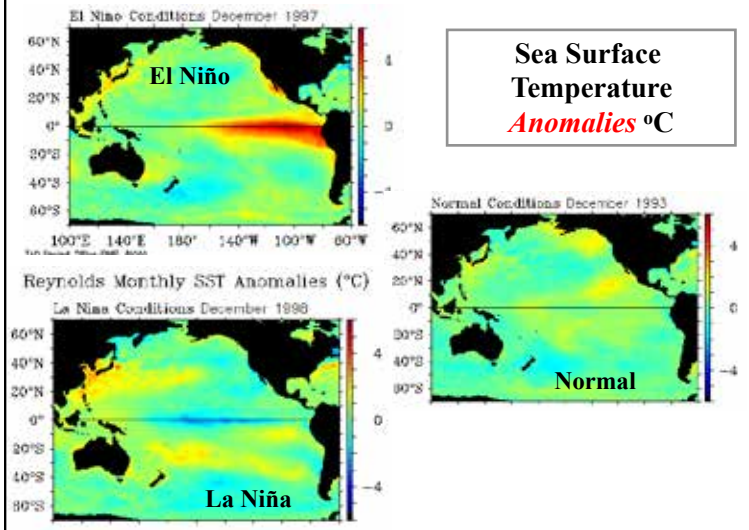


- No Coriolis force at Equator, so wind pushes water west
- Cold water gets pushed "out of the way" (downward) as warm water "piles up" on top

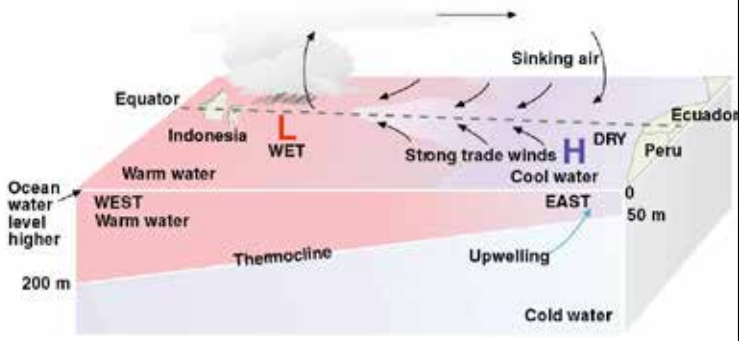
El Niño



- Normal conditions: Huge accumulation of deep warm water in W. Pacific
- El Niño: Relaxation of Trade Winds allows warm water to flow eastward

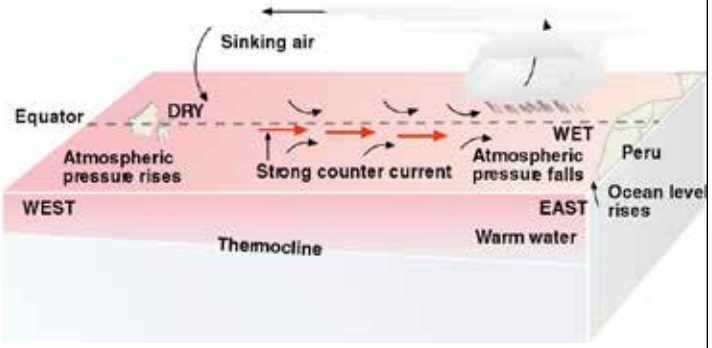


Normal (non-El Niño) Conditions



- Surface water flow from east toward west
- Deep thermocline and warm water in western Pacific (associated deep convection & rainfall)
- Shallow thermocline and cool SST's in east Pacific

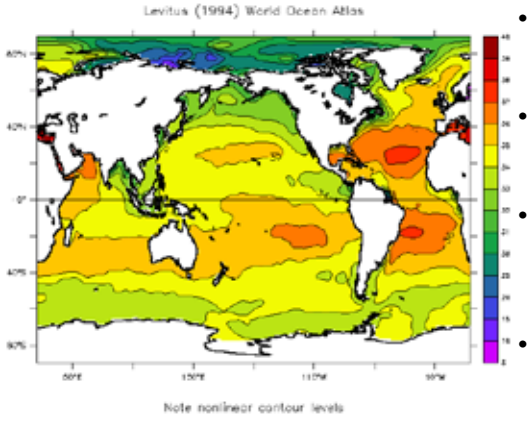
El Niño Conditions



- Surface water flow toward east
- Warm SSTs, convection & rainfall shift to central Pacific
- Warmer SST's in eastern Pacific

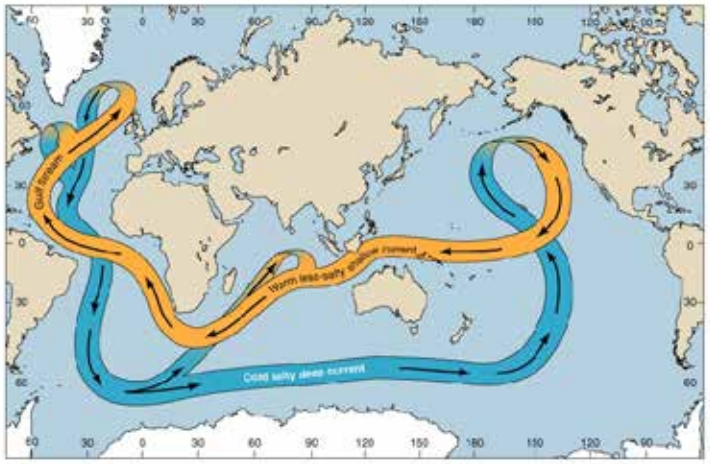
Thermohaline Circulation

Sea Surface Salinity

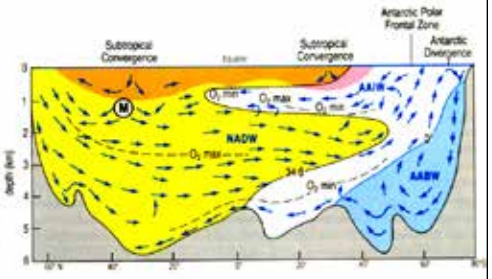


- Evaporation increases salinity
- Precipitation decreases it (dilution)
- Freshest water at highest latitudes
- Saltiest water in subtropics (especially in Atlantic)

Thermohaline Circulation



Atlantic Water Masses

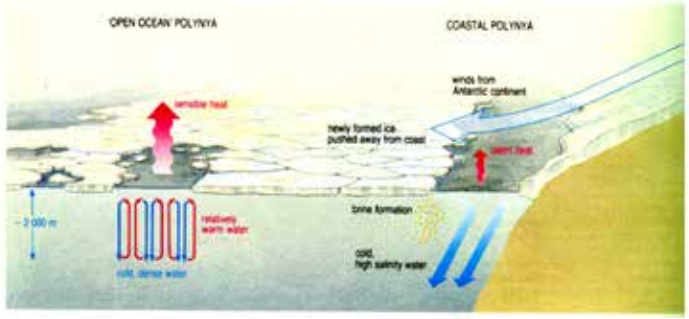


- Deep water formation in North Atlantic
- Bottom water formation in Antarctic
- Ekman convergence in subtropical gyres forces water down against buoyancy

Bottom Water Flow

Deep water formed off Greenland and Norway flows south to fill Atlantic Basin

Antarctic Bottom Water



Continuous formation of ice along coast and in "leads" or "polynyas" forms extremely dense water

Thermohaline Heat Pump

- Upper limb inflow to North Atlantic ~ 10° C
- Lower limb outflow ~ 3°C
- dQ = c dT ~ 3 x 10^7 J of heat released by each m^3 of water during conversion from upper limb to lower limb water mass
- 20 Sv = 20 x 10^6 m^3 s^{-1} of water makes this transition, releasing 6 x 10^{14} J s^{-1} (= 0.6 Pw) of heat to the atmosphere
- This is 35% of solar heating of North Atlantic north of 40° N latitude!