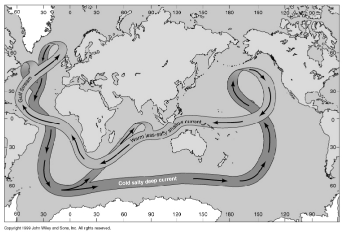
Lecture 4: OCEANS (Outline)



- ❑ Basic Structures and Dynamics
  - Ekman transport
  - Geostrophic currents
- ❑ Surface Ocean Circulation
  - Subtropicl gyre
  - Boundary current
- ❑ Deep Ocean Circulation
  - Thermohaline conveyor belt

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Basic Ocean Structures

Warm up by sunlight!

❑ **Upper Ocean (~100 m)**

Shallow, warm upper layer where light is abundant and where most marine life can be found.

❑ **Deep Ocean**

Cold, dark, deep ocean where plenty supplies of nutrients and carbon exist.

No sunlight!

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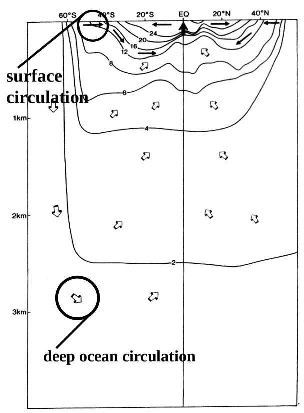
Basic Ocean Current Systems



Upper Ocean

Deep Ocean

(from *"Is The Temperature Rising?"*)

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The State of Oceans

❑ Temperature

warm on the upper ocean, cold in the deeper ocean.

❑ Salinity

variations caused by determined by evaporation, precipitation, sea-ice formation and melt, and river runoff.

❑ Density

small in the upper ocean, large in the deeper ocean.

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Potential Temperature

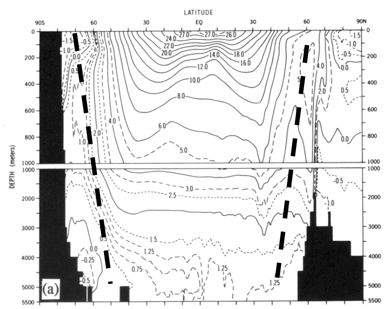

Fig. 7.1 Annual-mean zonal average for the global ocean of (a) potential temperature (°C), and (b) salinity [‰ (‰ = parts per thousand)], and (c) potential density (ρ_θ – 1000, kg m^{-3}). [From Levitus (1982).]

(from *Global Physical Climatology*)

- ❑ Potential temperature is very close to temperature in the ocean.
- ❑ The average temperature of the world ocean is about 3.6°C.

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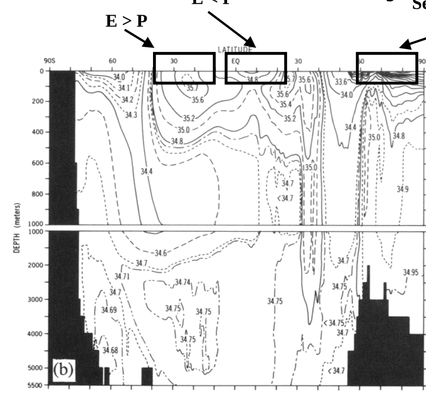
Salinity



(from *Global Physical Climatology*)

- ❑ Salinity is the mass of dissolved salts in a kilogram of seawater.
- ❑ Unit: ‰ (part per thousand; per mil).
- ❑ The average salinity of the world ocean is 34.7‰.
- ❑ Four major factors that affect salinity: evaporation, precipitation, inflow of river water, and sea-ice formation and melting.

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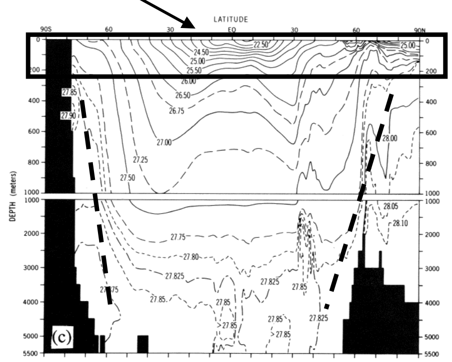
Density



(from *Global Physical Climatology*)

- ❑ Seawater is almost incompressible, so the density of seawater is always very close to 1000 kg/m^3.
- ❑ Potential density is the density that seawater with a particular salinity and temperature would have at zero water pressure (or at surface air pressure).
- ❑ Potential density = density – 1000 kg/m^3.

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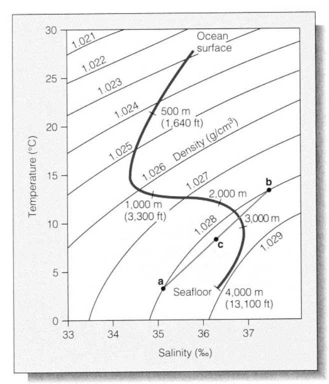
Density and Temperature and Salinity



(Figure from *Oceanography* by Tom Garrison)

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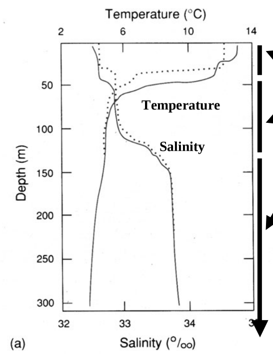
Vertical Structure of Ocean



Mixed Layer: T and S well mixed by winds

Thermocline: large gradient of T and S

Deep Ocean: T and S independent of height
cold
salty
high nutrient level

(from *Climate System Modeling*)

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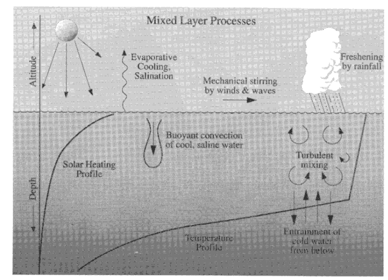
Mixed Layer Processes



(from *Global Physical Climatology*)

- ❑ The depth of the mixed layer is determined by (1) the rate of buoyancy generation and (2) the rate kinetic energy supply.
- ❑ The atmosphere can affect the mixed layer through three processes: heating, wind forcing, and freshening (P-E).
- ❑ The global-average depth of the mixed layer is about 70 m.
- ❑ The heat capacity of the mixed layer is about 30 times the heat capacity of the atmosphere.

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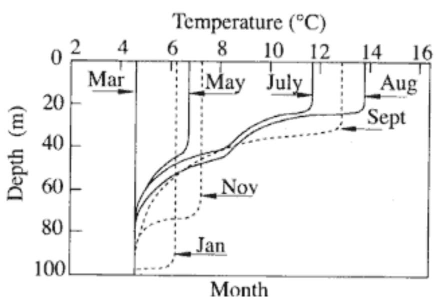
Seasonal Variation of Mixed Layer



- ❑ Summer: warm and thin.
- ❑ Winter: cold and deep (several hundred meters).

(from *Global Physical Climatology*)

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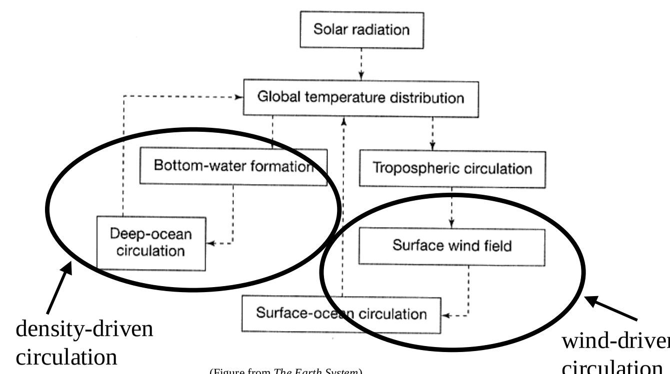
Two Circulation Systems



(Figure from *The Earth System*)

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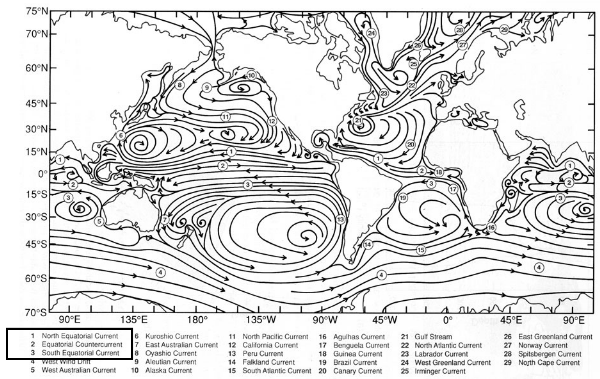
Global Surface Currents



(from *Climate System Modeling*)

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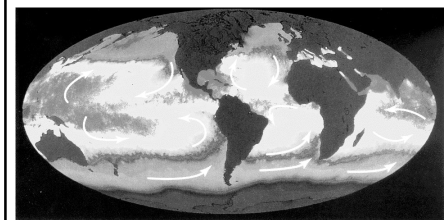
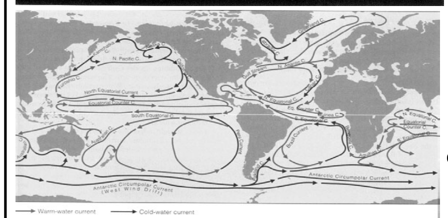
Six Great Current Circuits in the World Ocean





- **5 of them are geostrophic gyres:**
  - North Pacific Gyre
  - South Pacific Gyre
  - North Atlantic Gyre
  - South Atlantic Gyre
  - Indian Ocean Gyre
- **The 6th and the largest current:**
  - Antarctic Circumpolr Current
  - (also called West Wind Drift)

(Figure from *Oceanography* by Tom Garrison)

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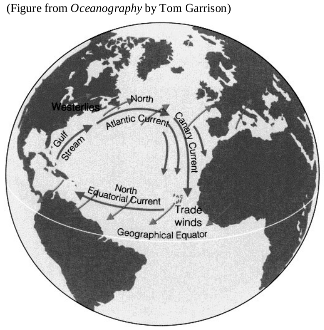
Characteristics of the Gyres

(Figure from *Oceanography* by Tom Garrison)



- **Currents are in geostropic balance**
- **Each gyre includes 4 current components:**
  - two boundary currents: western and eastern
  - two transverse currents: easteward and westward

Western boundary current (jet stream of ocean)
the fast, deep, and narrow current moves **warm** water polarward (transport ~50 Sv or greater)

Eastern boundary current
the slow, shallow, and broad current moves cold water equatorward (transport ~ 10-15 Sv)

Trade wind-driven current
the moderately shallow and broad westward current (transport ~ 30 Sv)

Westerly-driven current
the wider and slower (than the trade wind-driven current) eastward current

Volume transport unit:
1 sv = 1 Sverdrup = 1 million m^3/sec
(the Amazon river has a transport of ~0.17 Sv)

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Major Current Names

- **Western Boundary Current**
  - Gulf Stream (in the North Atlantic)
  - Kuroshio Current (in the North Pacific)
  - Brazil Current (in the South Atlantic)
  - Eastern Australian Current (in the South Pacific)
  - Agulhas Current (in the Indian Ocean)
- **Trade Wind-Driven Current**
  - North Equatorial Current
  - South Equatorial Current
- **Eastern Boundary Current**
  - Canary Current (in the North Atlantic)
  - California Current (in the North Pacific)
  - Benguela Current (in the South Atlantic)
  - Peru Current (in the South Pacific)
  - Western Australian Current (in the Indian Ocean)
- **Westerly-Driven Current**
  - North Atlantic Current (in the North Atlantic)
  - North Pacific Current (in the North Pacific)

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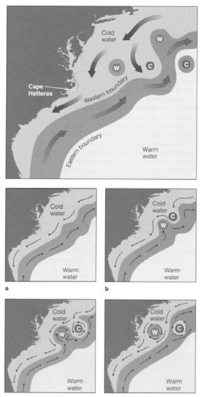
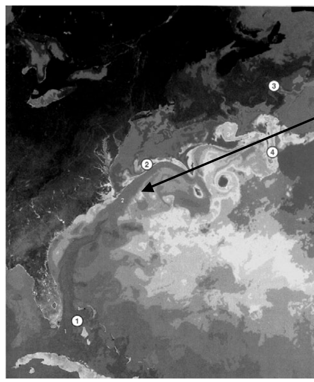
Gulf Stream





A river of current

Jet stream in the ocean

- Speed = 2 m/sec
- Depth = 450 m
- Width = 70 Km
- Color: clear and blue

(Figure from *Oceanography* by Tom Garrison)

Surface Current – Geostrophic Gyre

❑ Mixed Layer

Currents controlled by frictional force + Coriolis force
→ wind-driven circulation
→ Ekman transport (horizontal direction)
→ convergence/divergence
→ downwelling/upwelling at the bottom of mixed layer

❑ Thermocline

downwelling/upwelling in the mixed layer
→ pressure gradient force + Coriolis force
→ geostrophic current
→ Sverdrup transport (horizontal)

Step 1: Surface Winds

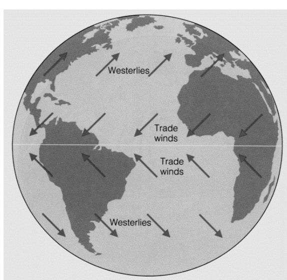


Figure 9.1 Winds, driven by uneven solar heating and Earth's spin, drive the movement of the ocean's surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

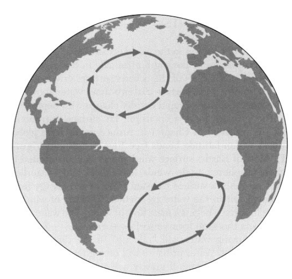
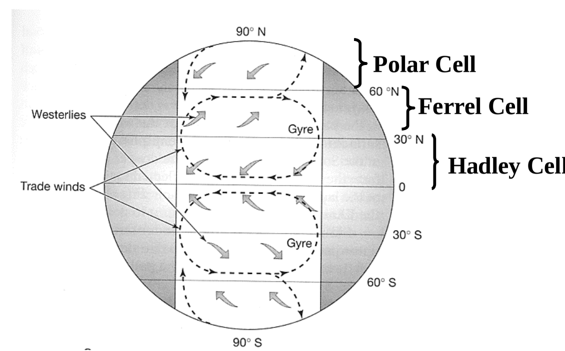


Figure 9.2 A combination of four forces—surface winds, the sun's heat, the Coriolis effect, and gravity—circulates the ocean surface clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming gyres.

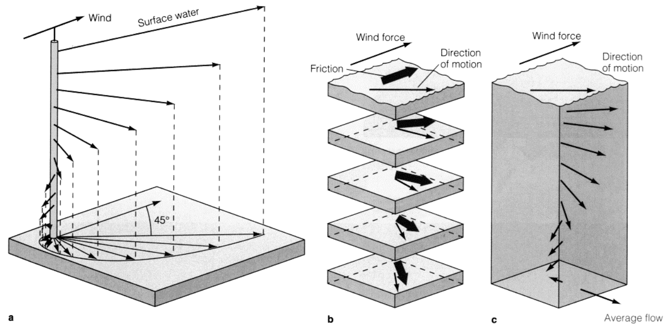
(Figure from *Oceanography* by Tom Garrison)

Winds and Surface Currents



(Figure from *The Earth System*)

Step 2: Ekman Layer
(frictional force + Coriolis Force)



(Figure from *Oceanography* by Tom Garrison)

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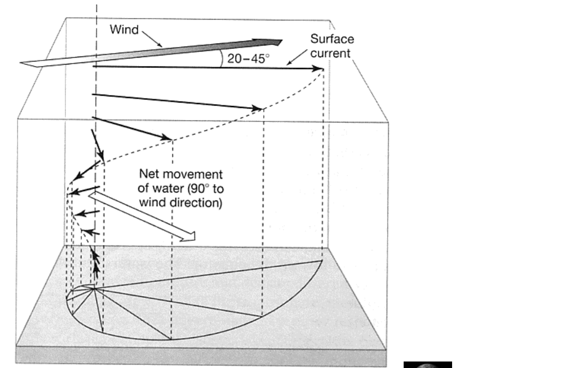
Ekman Spiral – A Result of Coriolis Force



(Figure from *The Earth System*)

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Formula for Ekman Transport

$$U_E = \int_{-\infty}^{0} u_E \, dz = \frac{\tau_y}{\rho_o f}; \qquad V_E = \int_{-\infty}^{0} v_E \, dz = -\frac{\tau_x}{\rho_o f}$$

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How Deep is the Ekman Layer?

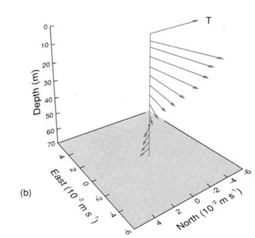

Fig. 4.4 (a) Vertical distribution of temperature and salinity at 50°N., 145°W. in early September, 1977. The solid lines are before a storm and the dotted lines are after a storm, which depict the vertical mixing above the seasonal thermocline. The main thermocline, or pycnocline in this area is between 110 m and 160 m depth. (b) Time-averaged velocity for a 25 day summer period at an open ocean site southwest of Bermuda. Current meter measured velocity is referenced to 70 m. The topmost dashed vector is the time-averaged wind stress (Price et al., 1986).

(from *Climate System Modeling*)

- ❑ $D \propto (\nu/f)^{1/2}$

ν = vertical diffusivity of momentum

f = Coriolis parameter = $2\Omega\sin\phi$

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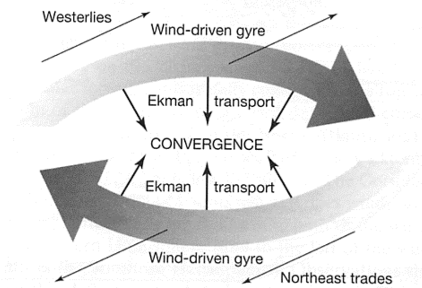
Ekman Transport



(Figure from *The Earth System*)

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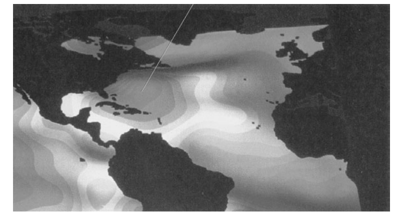
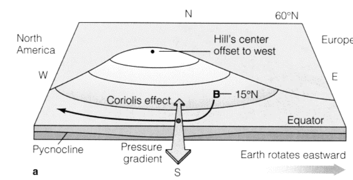
Step 3: Geostrophic Current
(Pressure Gradient Force + Corioils Foce)



NASA-TOPEX Observations of Sea-Level Hight



(from *Oceanography* by Tom Garrison)

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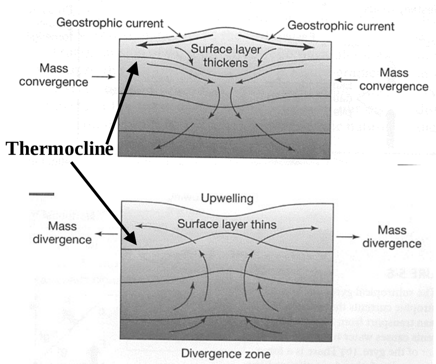
Ekman Transport → Convergence/Divergence

(Figure from *The Earth System*)



Surface wind + Coriolis Force

↓

Ekman Transport

↓

Convergence/divergence (in the center of the gyre)

↓

Pressure Gradient Force

↓

Geostrophic Currents

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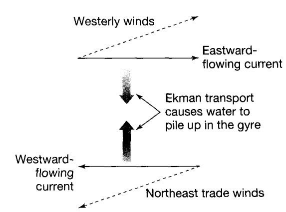
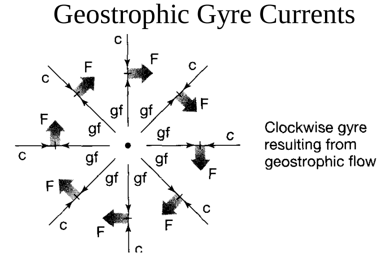
Geostrophic Current

Forces



Geostrophic Gyre Currents



(Figure from *The Earth System*)

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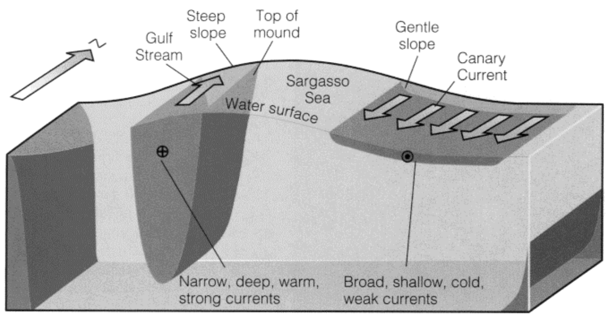
Step 4: Boundary Currents



(Figure from *Oceanography* by Tom Garrison)

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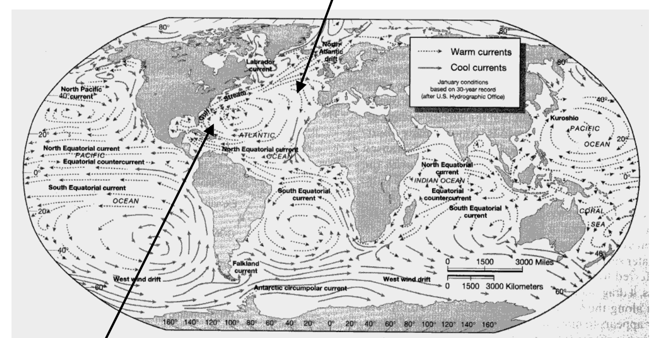
Boundary Currents

Eastern boundary currents: broad and weak



Western boundary currents: narrow and strong

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Eastern Boundary Current

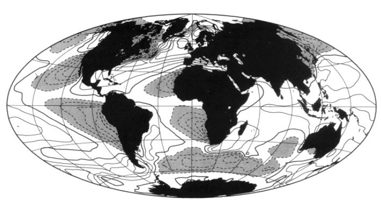

Fig. 7.11 The deviation of the July sea surface temperature from its zonal average at each latitude. Contour interval is 1°C, and values less than −1°C are shaded.

(from *Global Physical Climatology*)

- ❑ Cold water from higher latitude ocean.
- ❑ Costal upwelling associated with subtropical high pressure system.
- ❑ Atmospheric subsidence produce persistent stratiform clouds, which further cool down SSTs by blocking solar radiation.

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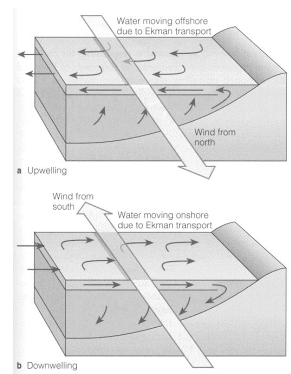
Costal Upwelling/Downwelling



- ❑ A result of Ekman transport and mass continuity.

(Figure from *Oceanography* by Tom Garrison)

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Interior Upwelling / Downwelling

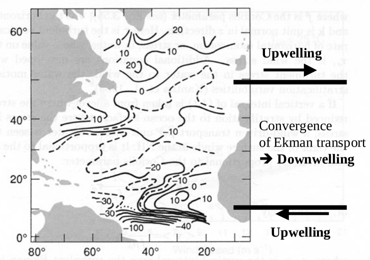

Fig. 4.7 Annual mean North Atlantic vertical velocity at the base of the Ekman layer. Positive is upward and the units are in 10^{-8} cm s^{-1}. Note that off South America the contours between −60 and −100 are left out because of crowding (Leetmaa and Bunker, 1978).

(from *Climate System Modeling*)

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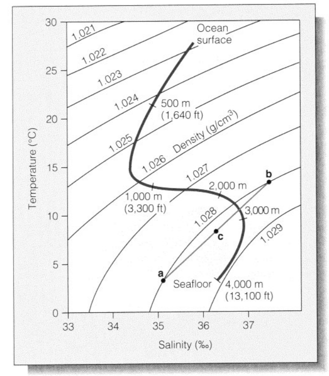
Deep Ocean Circulation: Density-Driven



(Figure from *Oceanography* by Tom Garrison)

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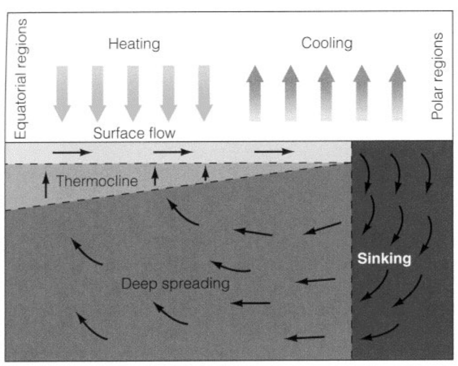
Thermohaline Circulation



(Figure from *Oceanography* by Tom Garrison)

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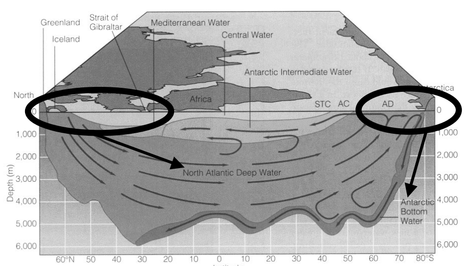
Two Regions of Deep Water Formation



(Figure from *Oceanography* by Tom Garrison)

- ❑ Antarctic Bottom Water
  - Salinity = 34.65‰
  - Temperature = -0.5°C
  - Density = 1.0279 g/cm^3
  - Formed at Weddell Sea
  - Related to ice formation
  - During Winter
- ❑ North Atlantic Deep Water
  - Due to winter cooling and evaporation.

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Two Processes to Increase Salinity in High Latitudes

- ❑ **Evaporation**: Extremely cold, dry winter air enhances evaporation from the relatively warm ocean ➔ increase salinity in the ocean.
- ❑ **Formation of Sea Ice**: When sea ice forms, salts are left in the ocean ➔ increase salinity

Ocean Water Mass

Surface Water
to a depth of about 200 meters

Central Water
to the bottom of the main thermocline

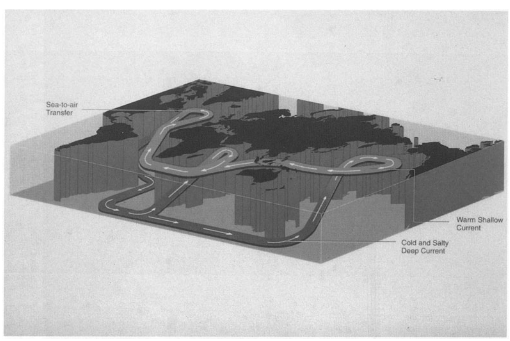
Intermediate Water
to about 1500 meters

Deep Water
below intermediate water but not in contact with the bottom

Bottom Water
in contact with sea floor

- Ocean water masses possess distinct, identifiable properties and don't often mix easily when they meet.
- In stead, they usually flow above or below each other.
- Ocean water mass can retain their identity for great distance and long periods of time.
- Oceanographers name water masses according to their relative position.

Thermohaline Conveyor Belt



(Figure from *Climate System Modeling*)

Thermohaline Circulation

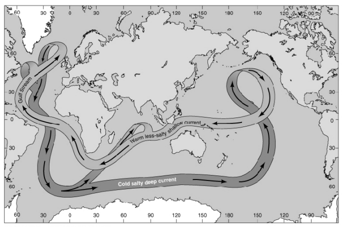
- ❑ Thermo ➔ temperature
- ❑ Haline ➔ salinity

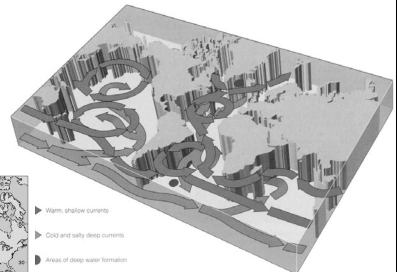
Density-Driven Circulation

Cold and salty waters go down
Warm and fresh waters go up

Thermohaline Conveyor Belt

- ❑ Typical speed for deep ocean current: 0.03-0.06 km/hour.
- ❑ Antarctic Bottom Water takes some 250-1000 years to travel to North Atlantic and Pacific.





(Figure from *Oceanography* by Tom Garrison)

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It Takes ~1000 Years for Deep Ocean Waters to Travel Around…

❑ If we date a water parcel from the time that it leaves the surface and sink into the deep ocean

➔ Then the youngest water is in the deep north Atlantic, and the oldest water is in the deep northern Pacific, where its age is estimated to be 1000 year.

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The Most Unpolluted Waters are..

the waters in the deep northern Pacific.

❑ The man-released CFC and the chemical tritium and C^{14}, which were released through atmospheric atomic bomb test in the 1950s and 1960s, entered the deep ocean in the northern Atlantic and are still moving southward slowly.

❑ Those pollutions just cross the equator in the Atlantic ➔ They have not reached the deep northern Pacific yet!!

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Global Warming and Thermohaline Circulation

❑ ***If the warming is slow***

The salinity is high enough to still produce a thermohaline circulation

➔The circulation will transfer the heat to deep ocean

➔The warming in the atmosphere will be deferred.

❑ ***If the warming is fast***

Surface ocean becomes so warm (low water density)

➔No more thermohalione circulation

➔The rate of global warming in the atmosphere will increase.

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