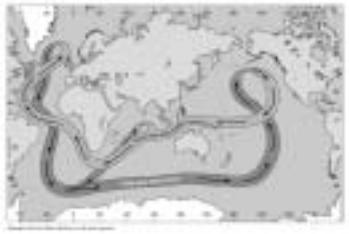
Lecture 7: The Ocean In Motion



- Basic Structures
- Surface Ocean Circulation
- Deep Ocean Circulation

ESS11
Prof. Jin-Yi Yu

Basic Ocean Structures

Warm up by sunlight!

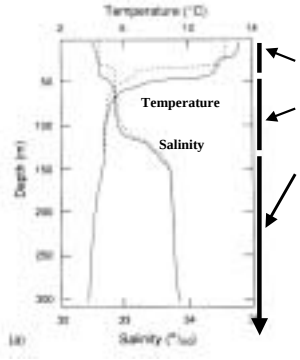
- **Upper Ocean (~100 m)**
  Shallow, warm upper layer where light is abundant and where most marine life can be found.

- **Deep Ocean**
  Cold, dark, deep ocean where plenty supplies of nutrients and carbon exist.

No sunlight!

ESS11
Prof. Jin-Yi Yu

Vertical Structure of Ocean



Mixed Layer: T and S well mixed by winds

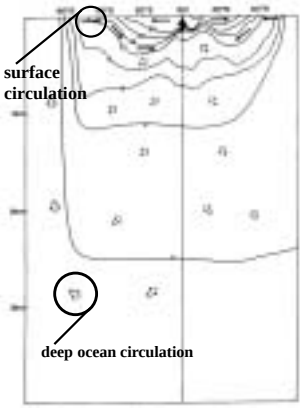
Thermocline: large gradient of T and S

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

(from *Climate System Modeling*)

ESS11
Prof. Jin-Yi Yu

Basic Ocean Current Systems



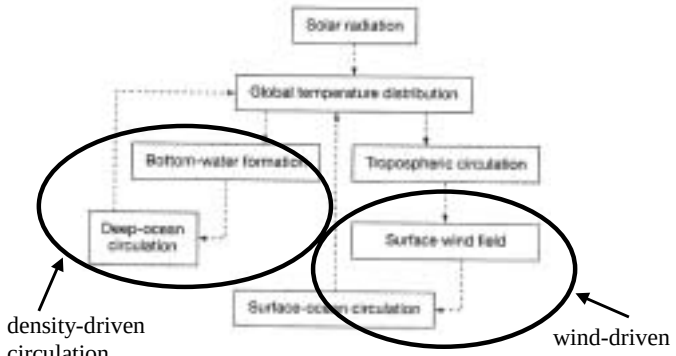
Upper Ocean

Deep Ocean

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

ESS11
Prof. Jin-Yi Yu

Two Circulation Systems

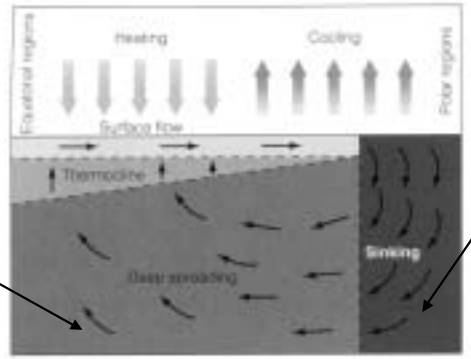


density-driven circulation

wind-driven circulation

(Figure from *The Earth System*)

Thermohaline Circulation



Youngest Waters

Oldest Waters

(Figure from *Oceanography* by Tom Garrison)

Thermohaline Circulation

- Thermo ➔ temperature
- Haline ➔ salinity

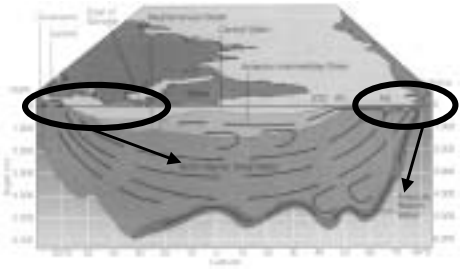
Density-Driven Circulation

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

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

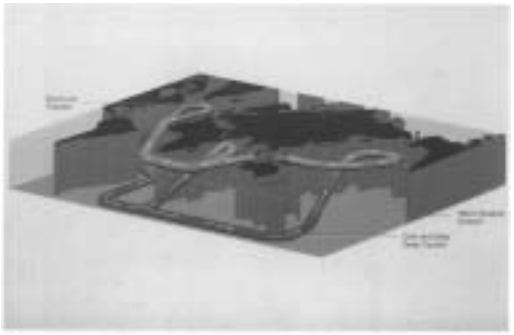
Two Regions of Deep Water Formation



(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.

Thermohaline Conveyor Belt



(Figure from *Climate System Modeling*)

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.

The Most Nutritious Waters are…

the waters in the deep northern Pacific.

- The concentration of nutrients is at a minimum in the deep northern Atlantic because the water there has just arrived from the nutrient-depleted surface layers.
- On its subsequent journey, the water is then steadily enriched by sinking organic materials and reaches it maximum concentration at the deep northern Pacific.

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!!

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.

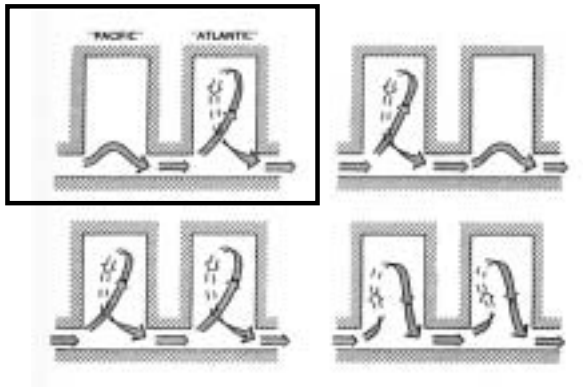
- ***If the warming is fast***

  Surface ocean becomes so warm (low water density)

  ➔ No more thermohalione circulation

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

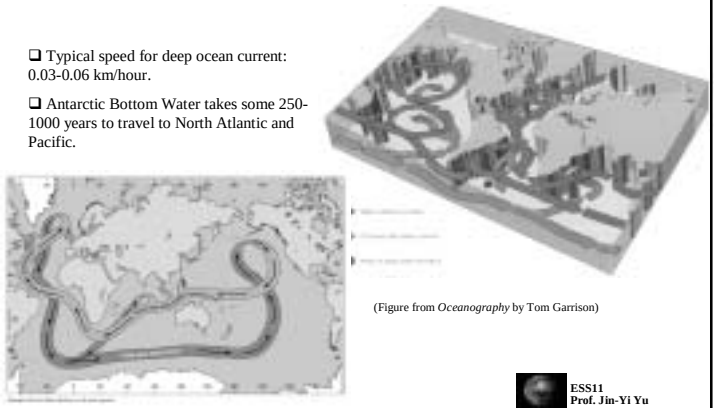
Four Possible Thermohaline Circulations



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

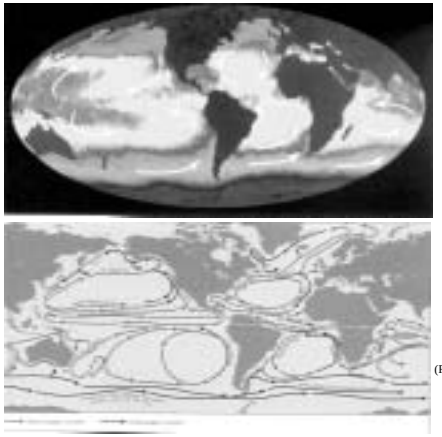
Thermohaline Conveyor Belt

- 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)

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)

Characteristics of the Gyres

(Figure from *Oceanography* by Tom Garrison)

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

- **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)

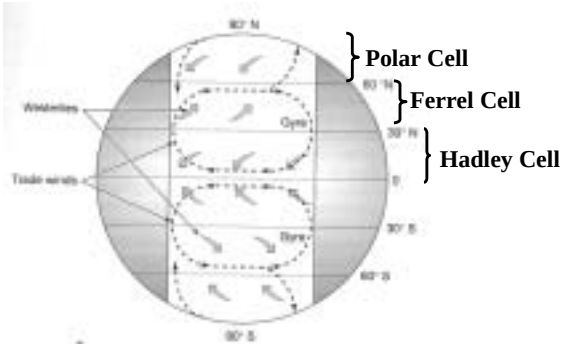
Trade wind-driven current
the moderately shallow and broad westward current (transport ~ 30 Sv)

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

Major Current Names

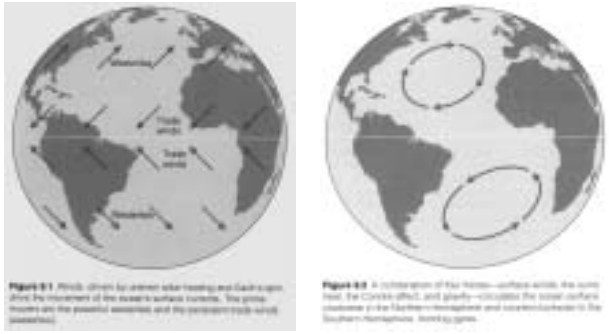
- **Western Boundary Current**
  - Gulf Stream (in the North Atlantic)
  - Kuroshio Current (in the North Pacific)
  - Brazil Current (in the South Atlantic)
  - Eastern Australian Current (in the South Pacific)
  - Agulhas Current (in the Indian Ocean)
- **Trade Wind-Driven Current**
  - North Equatorial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

Winds and Surface Currents



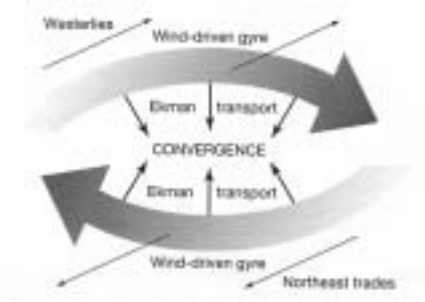
(Figure from *The Earth System*)

Surface Wind And Surface Current



(Figure from *Oceanography* by Tom Garrison)

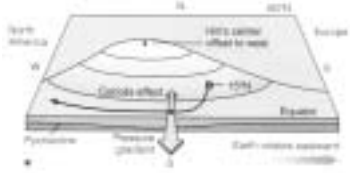
Ekman Transport



(Figure from *The Earth System*)

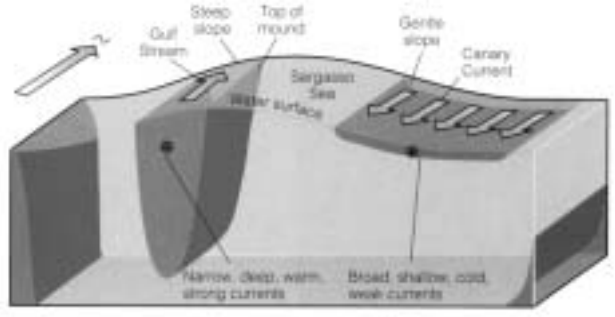
Ocean Surface Is Not Level

NASA-TOPEX Observations of Sea-Level Hight



(from *Oceanography* by Tom Garrison)

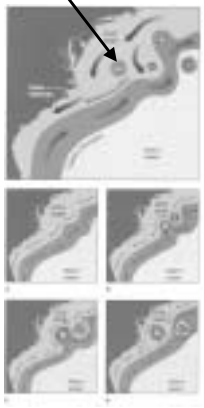
Boundary Currents

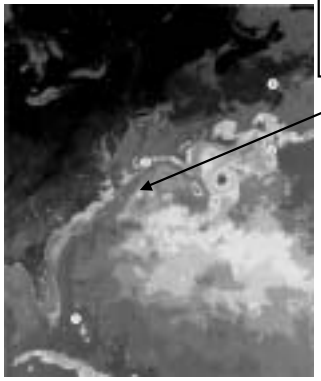


(Figure from *Oceanography* by Tom Garrison)

Gulf Stream

ocean weather / ocean eddy





A river of current

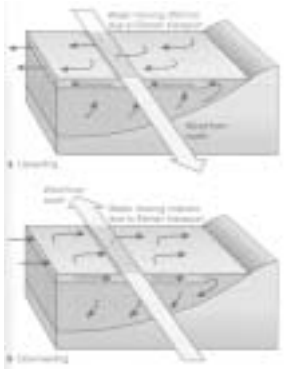
Jet stream in the ocean

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

(Figure from *Oceanography* by Tom Garrison)

ESS11
Prof. Jin-Yi Yu

Costal Upwelling/Downwelling



❑ A result of Ekman transport and mass continuity.

(Figure from *Oceanography* by Tom Garrison)

ESS11
Prof. Jin-Yi Yu