12.742 - Marine Chemistry Fall 2004

Lecture 5 - Marine Chemistry

Prof. Scott Doney

- Overview
  - Finish atmosphere (circulation, net fresh water)
  - Ocean equation of state
  - T, S, or ρ distributions
  - Wind-driven circulation
  - Deep-water thermocline
- Atmosphere
  - Circulation on a rotating planet - Northern Hemisphere
    - Rotation turns flow in the Northern hemisphere to the right (Coriolis force); rotation turns flow in the southern hemisphere to the left.
    - Rotation effects are strongest at the poles and diminish towards the equator.

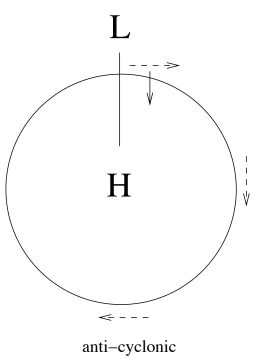

Figure 1.

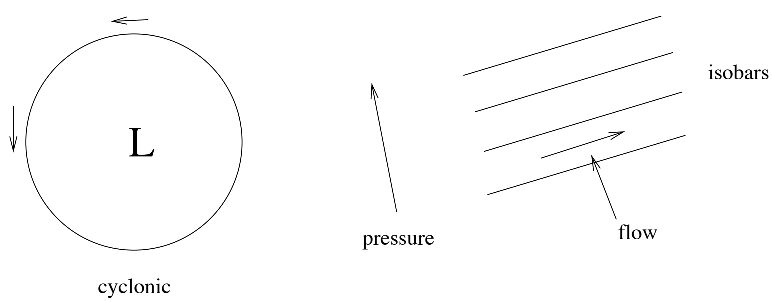

Figure 2.

  - Large imbalances in net heating/cooling drive

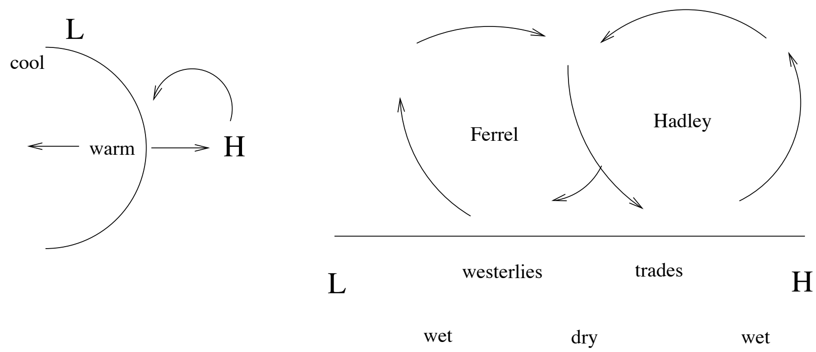

Figure 3.

flow

- In atmosphere, convention is to report direction as where the fluid is coming from (e.g. "north wind"); in ocean convention is to report direction as where the fluid is moving (e.g. "eastward current")

Net P-E

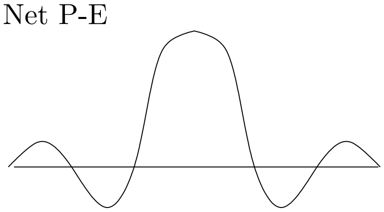

Figure 4.

- Ocean density equation of state
  - Ocean physics driven by wind stress, buoyancy (density) fluxes, rotation
  - $\rho(T, S, P)$ - empirically based
  - Freshwater ~ 1000 kg/m^3
  - Seawater roughly $1022 - 1028$ kg/m^3 at surface
  - Density anomaly:
$$\sigma(T, S, P) = \rho(T, S, P) - 1000$$
  - Potential temperature (θ)
$$\theta(T, S, P) \Rightarrow \theta(T, S, 0) \text{ for adiabatic path}$$
  - Compressibility
    Salinity = 35 T = 2°C $\rho = 1027.972$ Pressure = 0 bar
    Salinity = 35 T = 2°C $\rho = 1050.284$ Pressure = 400 bar

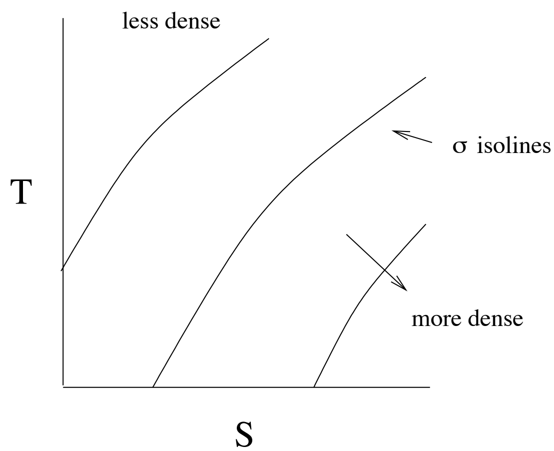

Figure 5.

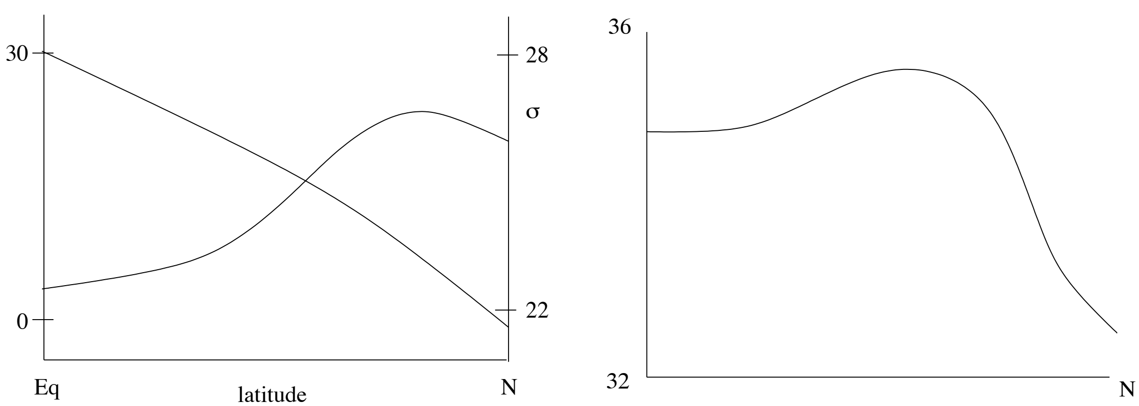

Figure 6.

- Temperature and Salinity distributions
- SST map - upwelling regions
- Temperature with depth
  - Main thermocline, seasonal thermocline, gyres, low versus high latitude

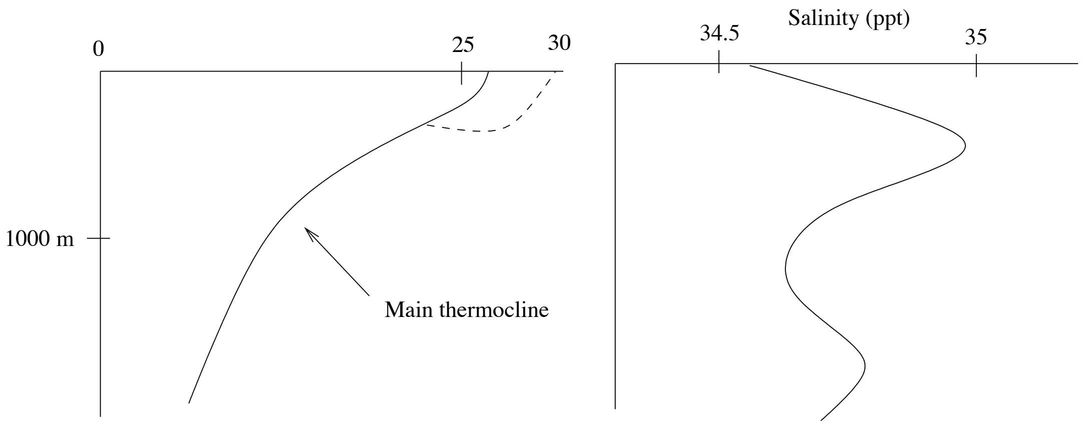

Figure 7.

- T - S diagrams
- 2 and 3 end-member mixing

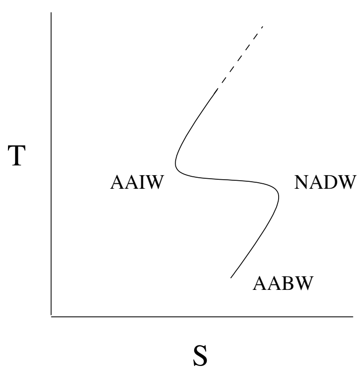

Figure 8.

Ocean well stratified.
Weak diapycnal diffusion in ocean interior (away from surface and bottom boundary layers).
Diffusivity order 10^{-5} m^2/s.
Some intensification over rough topography due to tidal generated internal waves.

- Wind-driven circulation

  Most ocean currents are geostrophic where pressure balances the Coriolis force and the flow is perpendicular to the pressure gradient (along constant pressure lines)

  – Ekman spiral

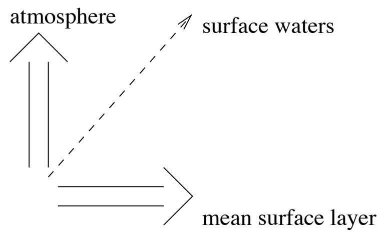

Figure 9.

  – Ekman pumping

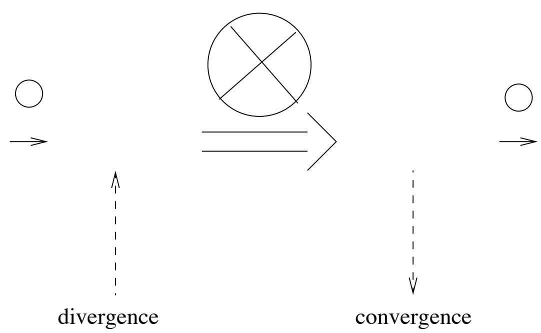

Figure 10.

  – Subtropical and subpolar gyres

Subtropical - downwelling and anti-cyclonic west(?) intensified

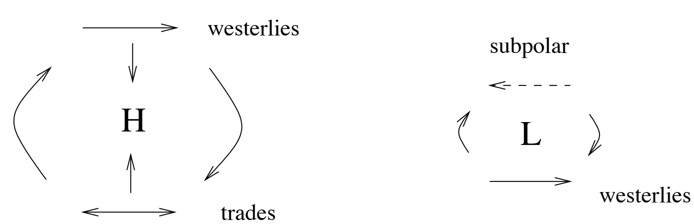

Figure 11.

  – ACC - circumpolar

    Much of ocean circulation is dominated by mesoscale eddies $10-200$ km - Don't believe simple "cartoons" of circulation

  – Schmitz diagram

    Upwelling/downwelling combination of wind stress and rotation

· Divergence of flow
· Cool equatorial waters

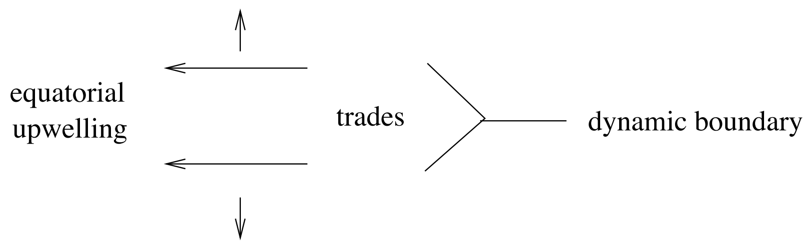

Figure 12.

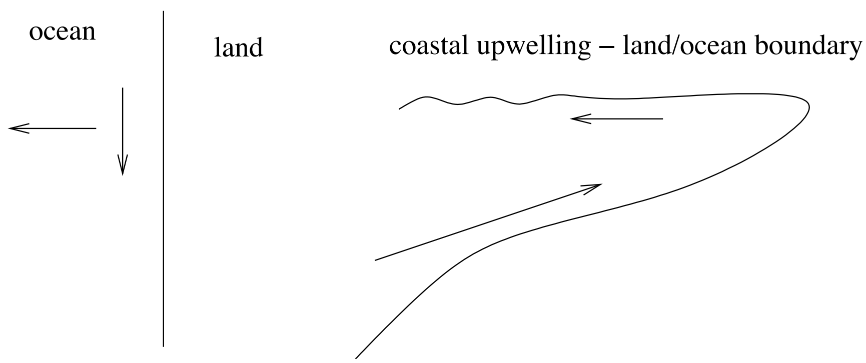

Figure 13.

- Deep water formation
  - Occurs in North Atlantic and Southern Ocean but not North Pacific (because of low surface salinities) (Surface salinity map)

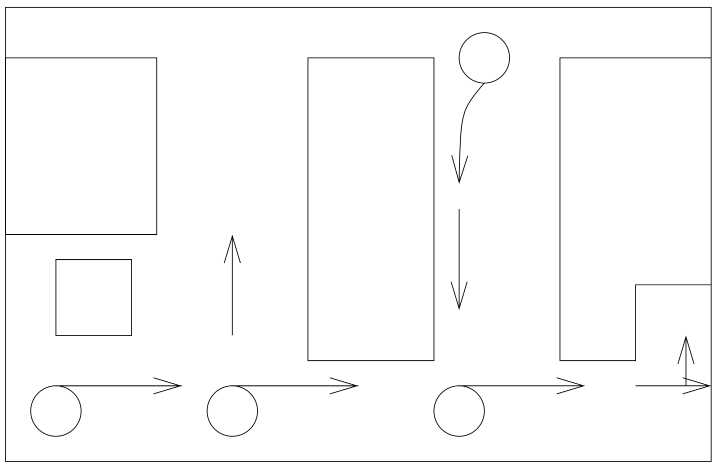

Figure 14.

North Atlantic Salinity/Temperature map

Size of water transports

Sv is a Sverdrup, a unit of volume transport

1 Sv $= 1 \times 10^6$ m^3/s

Amazon ~ 0.2 Sv

Gulf Stream ~ 100 Sv

Acc $\sim 120 - 140$ Sv

Mesoscale eddies

$50 - 100$ km's geostrophic balance

Isopycnal mixing O(1000 m^2/s)

(but only if on scale bigger than mesoscale eddies)

Dyapycnal mixing O($10^{-5} - 10^{-4}$ m^2/s)

  - Gyre circulation
    - Western intensification of flow; amplification of flow w/lots of recirculation

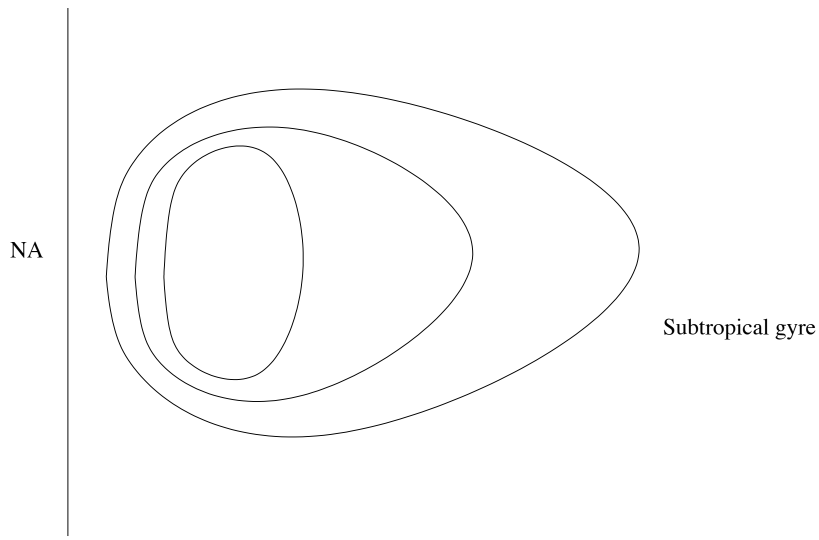

Figure 15.

- Chemical measyres of ocean ventilation rates
    - Transient tracers
    - Natural radiocarbon ^{14}C decays with $\sim$ 5000 year half-life. 1000 years is good for deep/bottom waters, which have ages of a few hundred to 1000 years; decay counting; accelerator mass spectrometry (AMS)
    - CFCs - chlorofluorocarbons (freons) - can measure at very low levels CFC-12, CFC-11, CFC-112,CCl_4 using gas chromatography (for fluorinated compounds use electron capture detector)
      decadal time-scale

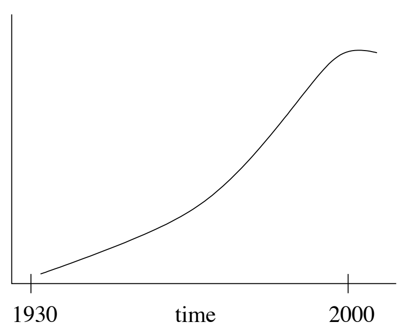

Figure 16.

- tritium - ^3He
  Atmospheric weapons testing produced ^3H - most injected in stratosphere
  use ^3H as "dye-tracer"
  also $^3H -^3 He$ age: $^3H \rightarrow^3 He$ with $\sim$ 12 year half-life
  For closed system -

$$^3H =^3 H(t_0)e^{-\lambda t}$$
$$\text{excess } ^3He = 0 +^3 H(t_0)e^{-\lambda t}$$

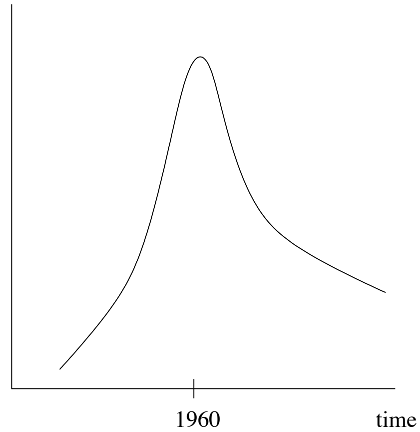

Figure 17.

^3He reset to solubility at surface by gas exchange
Sum of ^3H + excess ^3He is a constant equal to ^3H at time 0 (last exposure to atmosphere)

$$\frac{^3H}{^3H + ^3He} = e^{-\lambda t}$$
$$\log\left(\frac{^3H}{^3H + ^3He}\right) = -\lambda t$$
$$\Rightarrow \text{age}\tau = -\frac{1}{\lambda}\log\left(\frac{^3H}{^3H + ^3He}\right)$$

- Bomb-radiocarbon
  - Also released during atmospheric weapons testing
  - Gas exchange of $^{14}CO_2 \rightarrow$ ocean through subsequent circulation into thermocline and deep waters
  - Some biological redistribution via particles and remineralization

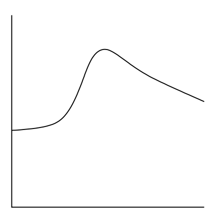

Figure 18.

- Trace release experiments
  - SF_6 - diapycanal diffusion experiments, eddy mixing and dispersion; gas exchange, deliberate injection of “dye” like traces