Ocean Dynamics

The Great Wave
off Kanagawa

Hokusai

LO: integrate relevant oceanographic processes with factors
influencing survival and growth of fish larvae

Physics Determining Ocean Dynamics

1. Conservation of mass
2. Conservation of energy
3. Newton’s First Law of Motion - if no force then no movement
4. Newton’s Second Law of Motion - rate of change of motion $\propto$ resultant force and direction
5. Newton’s Third Law of Motion - any force on a body, equal and opposite force on another body
6. Conservation of angular momentum
7. Newton’s law of Gravitation

Pond & Pickard 1983

Physical Processes & ELH Behavior

Environment	Pelagic	Nearshore	Estuary
Development stage	Yolk-sac and young larvae	Older and metamorphosing larvae	Post-larvae and juveniles
Physical process	Oceanographic (upwelling, surface drift)	Longshore currents	Tidal flux
Activity transport	Drift	Inshore movement	Tidal stream transport
Behaviour	Vertical movements	Circadian activity rhythms	Circatidal activity rhythms
Potential stimuli	Light, temperature, prey distribution	Diel cue (e.g. light)	Tidal cue (e.g. temperature, salinity)

Boehlert & Mundy 1988

Take Home Message:

physical processes increase nutrient availability and retention in surface layer; primary production is enhanced, secondary production enhanced, results in dense potential prey fields for fish larvae

Forces & Motions

Primary (causes motion)

1. Gravitation - earth (pressure), sun, moon
2. Wind Stress - tangential (friction), normal (pressure)
3. Atmospheric Pressure
4. Seismic - from sea bottom movements

Secondary (after motion initiated)

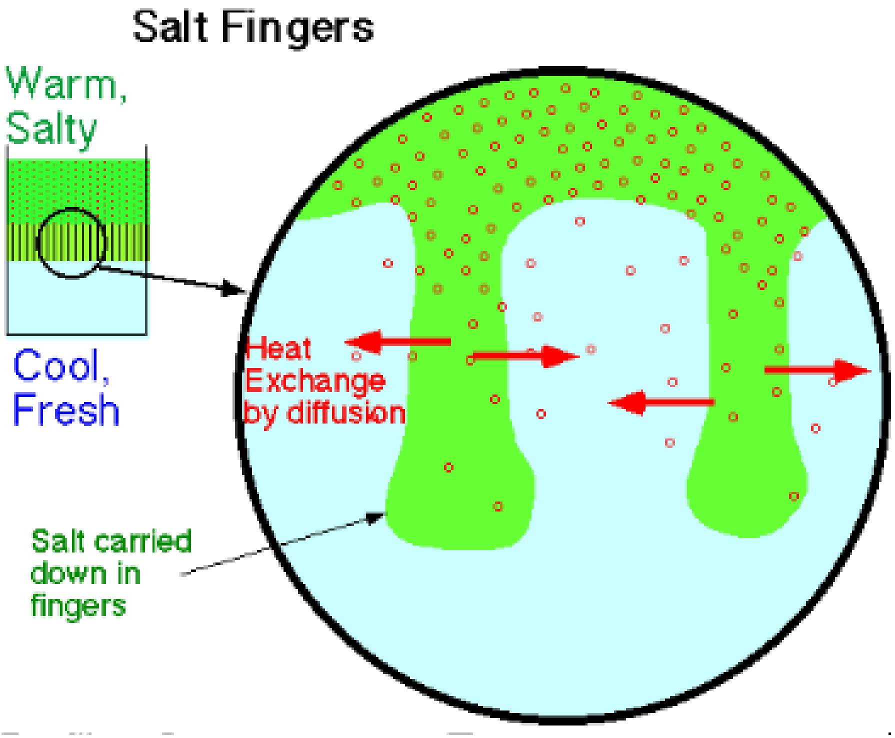
5. Coriolis force - due to earth rotation
6. Friction - at fluid boundary (opposes) or within (more uniform)

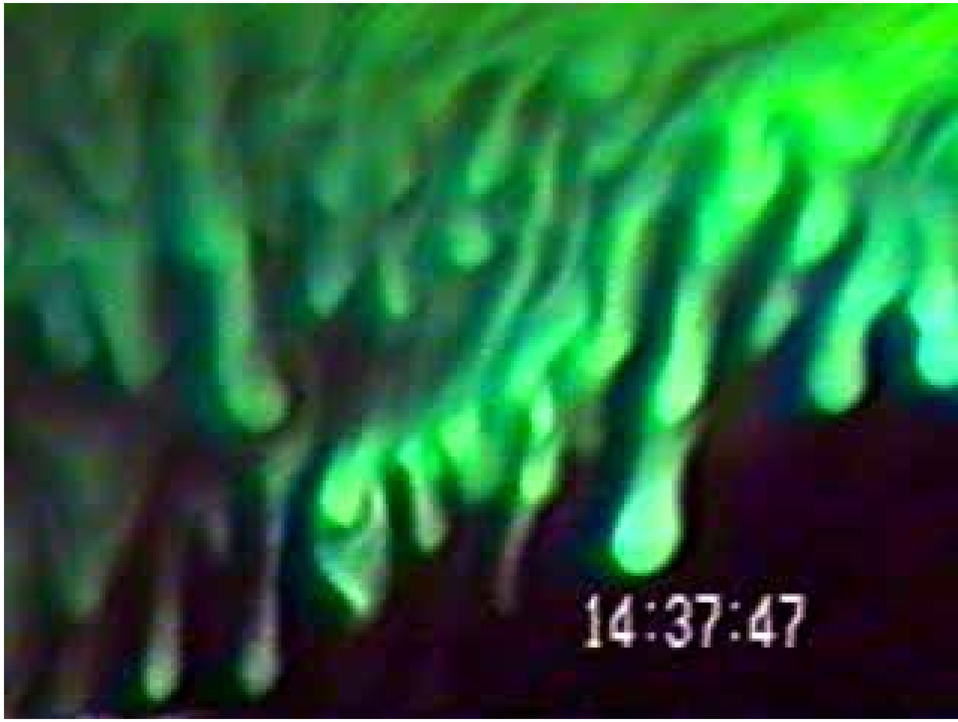
Pond & Pickard 1983

Causes of Water Movement

- density differences (temperature, salinity, depth)
- convection
- wind (fluid friction ~3%, stress (non-normal forces)

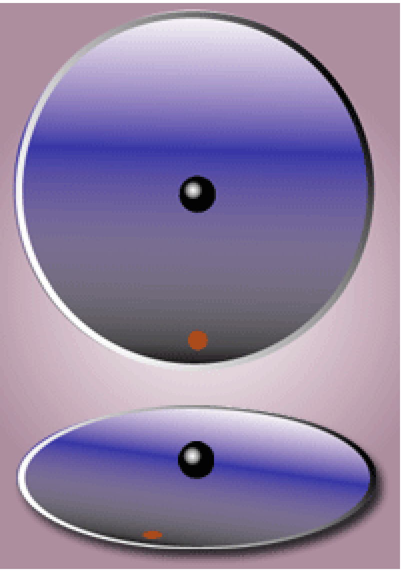
Salt Fingering



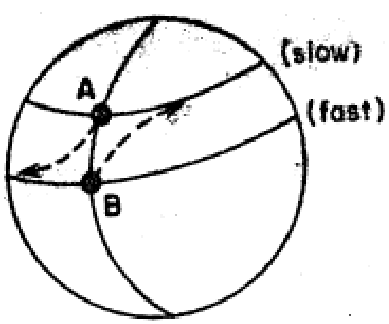


Dalhousie Oceanography, Barry Ruddick

Coriolis Force



- combined effects of gravity and a rotating planet
- due to reference frame: Eularian
- to the right in the northern hemisphere
- determined by Rossby number (low Ro, high effect)
- ratio of centrifugal to Coriolis accelerations



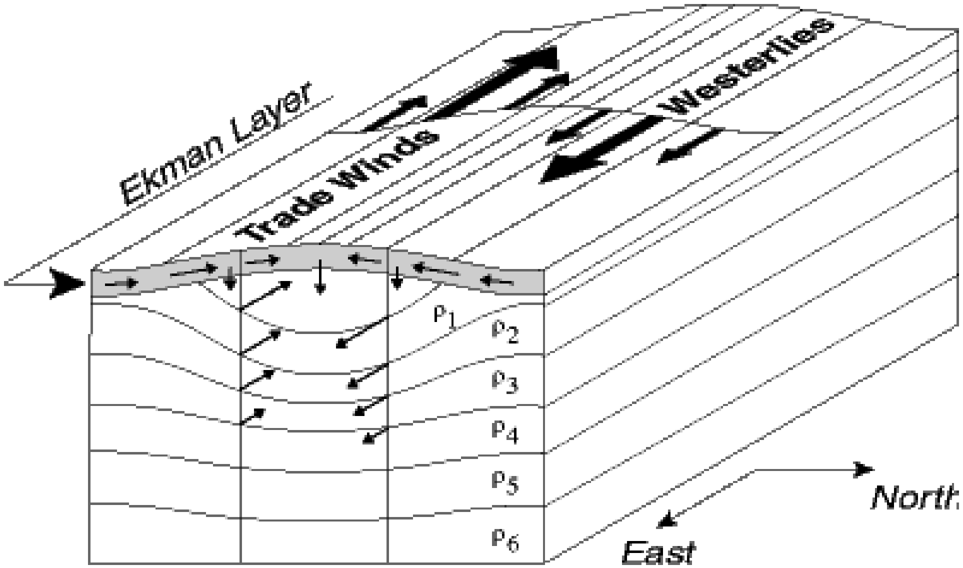
$$Ro = \frac{U}{fL}$$

U velocity, *f* Coriolis parameter ($2\Omega\sin(\Phi)$), *L* Length scale

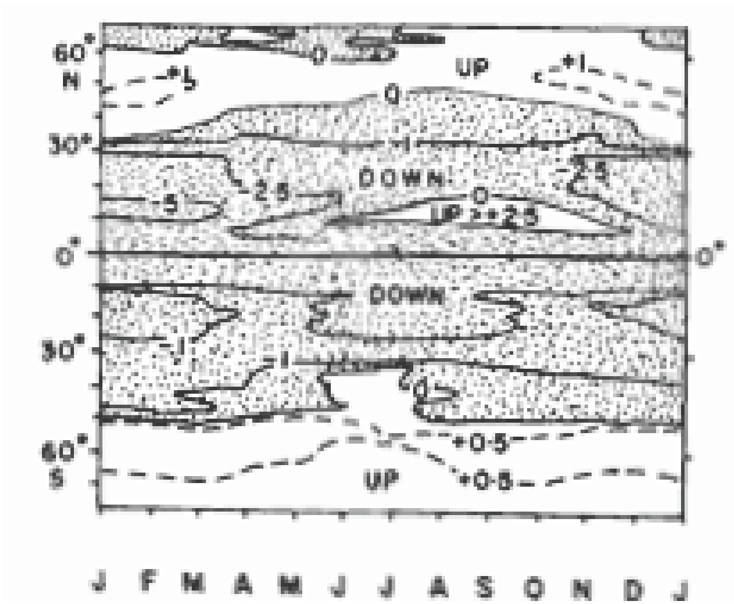
angular velocity, latitude

ocean ~1, atmospheric cell 0.1, playing catch ~6000

Ekman Transport



- thin (~100 m), wind driven frictional layer at the top of the ocean
- transport is at right angles to wind but variation in wind causes convergences and divergences



Pacific: net Ekman transport

convergence = downwelling
divergence = upwelling

Sverdrup Transport

Sverdrup relates meridional (i.e. longitude, north-south) depth integrated transport to the curl of the wind stress

- but, flow has to return via a boundary layer current.
- **western boundary** layer is only valid return path.
- additional processes in momentum & vorticity equations required: these can be bottom friction, lateral friction or inertial (non-linear) terms.

$$\beta V \mathbf{k} = \nabla \tau$$

β is the rate of change of the Coriolis parameter *f*, with meridional distance

V is the vertically integrated meridional mass transport

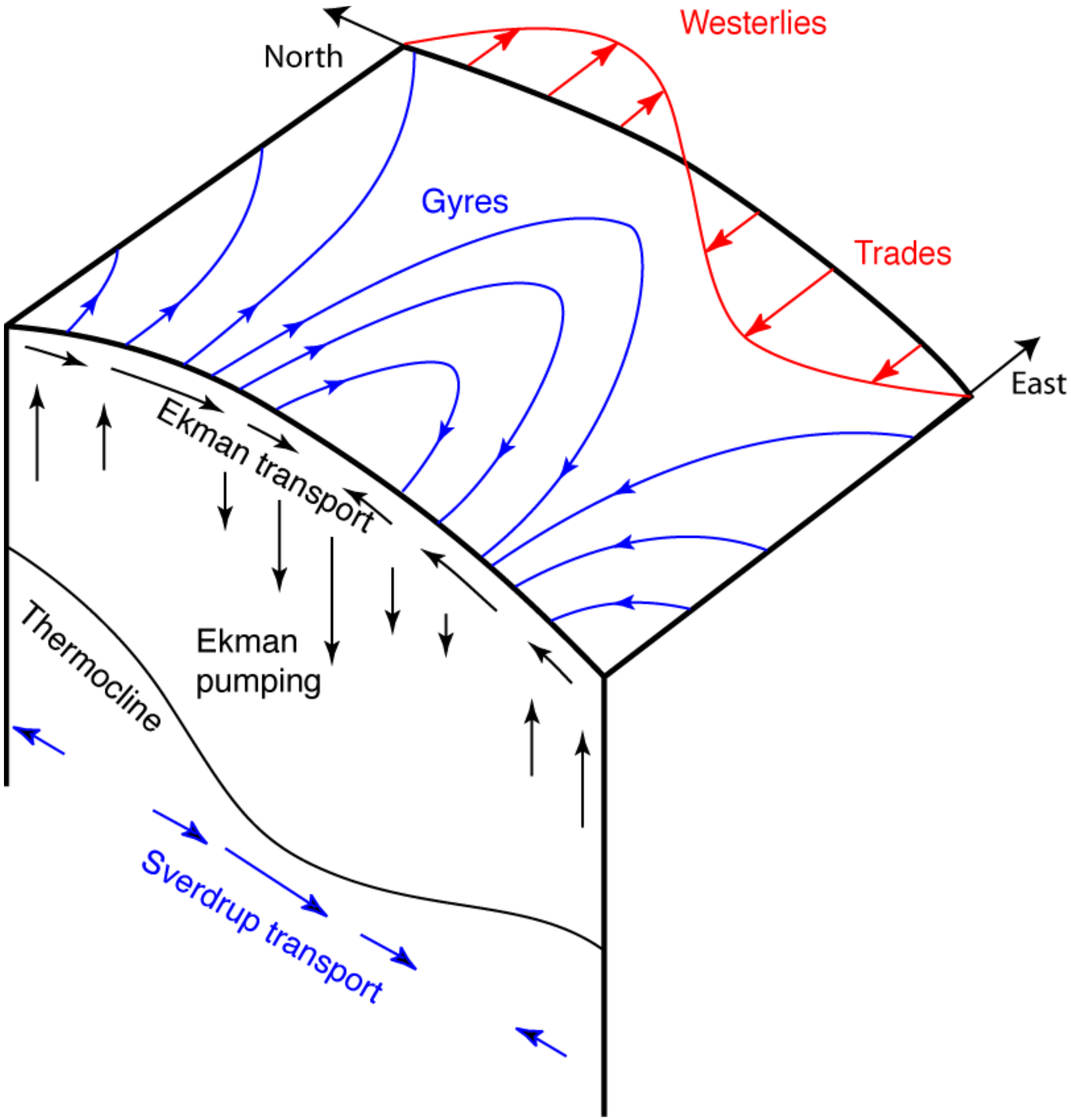
$\mathbf{k}$ is the unit vector in the *z* (vertical) direction

τ is the wind stress.

Assumes that:

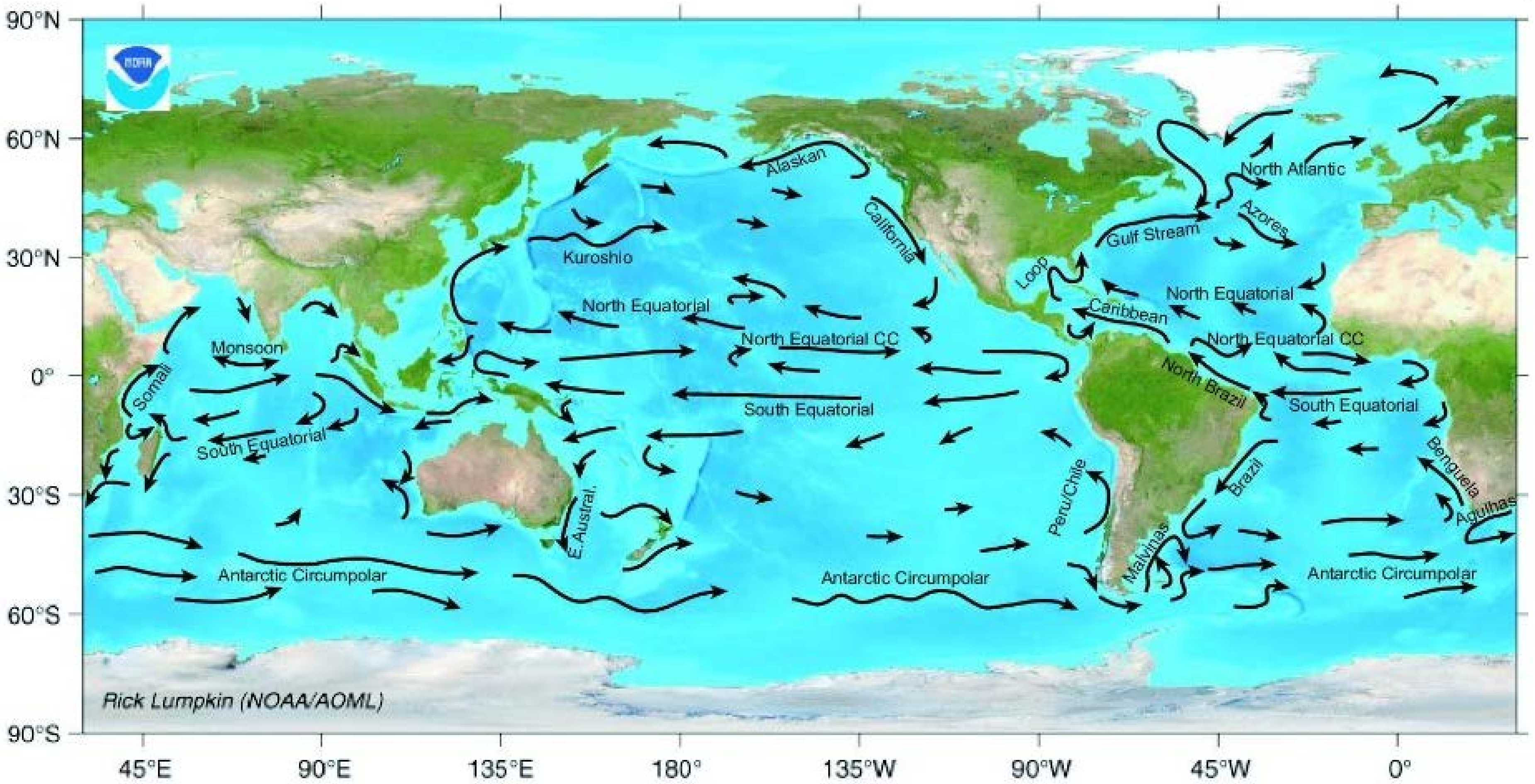
- wind stress is primary force
- friction is negligible

Ocean Water Transport



Intensified **western boundary currents**: the return flow for the interior Sverdrup transport

World Ocean Circulation



- intensification of **western boundary currents**, regardless of hemisphere

Ocean Circulation Understanding

- 1948 Henry Stommel added bottom friction to Sverdrup's ocean circulation model

- showed that variation in Coriolis parameter with latitude resulted in narrow western boundary current

- 1950 Walter Munk combined results of Rossby (eddy viscosity), Sverdrup (upper ocean wind driven flow), and Stommel (western boundary current flow) for a complete solution for ocean circulation.

Geographical Scales of Recruitment

What transport mechanisms interact with organism behavior to influence growth, survival, and ultimately recruitment?

internal waves, currents, fronts, upwelling, gyres, eddies

Internal Waves

- Garrett & Munk (1972; 1975) universal form for internal wave motion spectrum in mid-ocean: when $f < \omega < N$ (f inertial frequency, ω angular frequency, N buoyancy frequency), spectrum $\propto \omega^{-2}$
- internal wave energy expected near inertial frequency: 15 to 20 h in mid-latitudes
- coastal ocean more complex due to boundaries

Atlas of Internal Solitary Waves
Global Ocean Associates

Potential effects:

- horizontal nutrient, sediment transport
- vertical mixing
- passive particle vertical displacement: enhanced phytoplankton production, photo-inhibition

Currents

Drift Currents

- wind forced, permanent or predominant winds
- surface circulation and depth to approx. 60 - 70 m

Gradient Currents

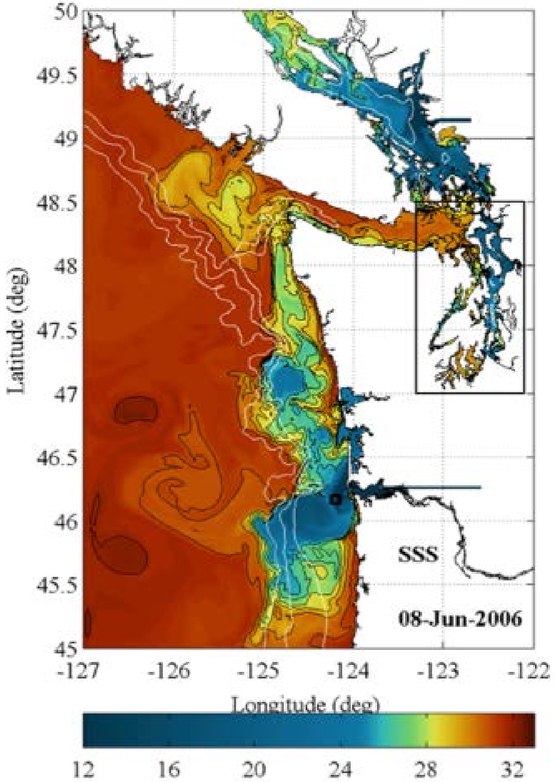
- pressure gradients on water masses

Fronts

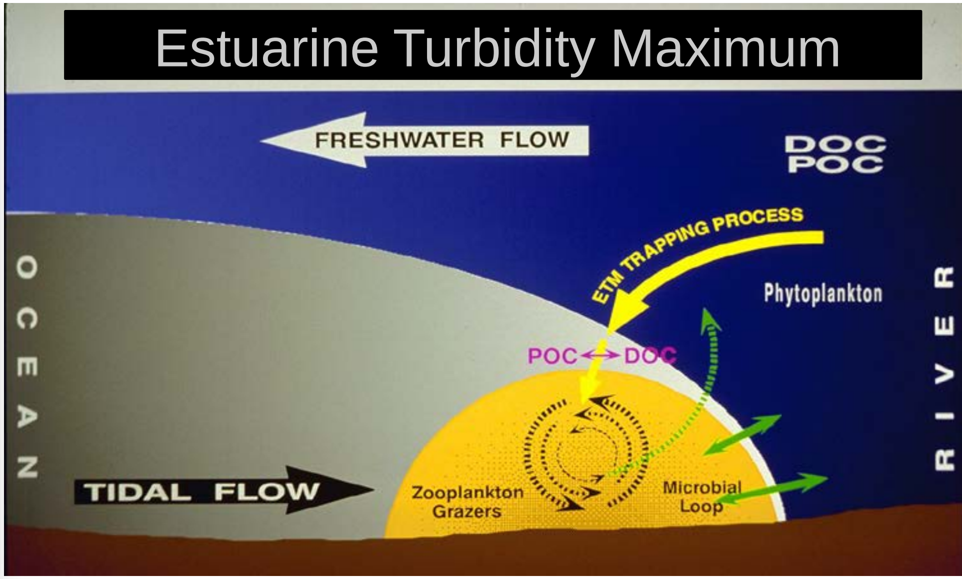
- discontinuity in the horizontal distribution of water mass properties at the scale of observation (Denman & Powell 1984)
- thermal fronts, haline fronts

Examples: estuaries – tide lines few meters wide, open ocean – oceanic regimes several degrees of latitude (lengths exceed widths in all cases)

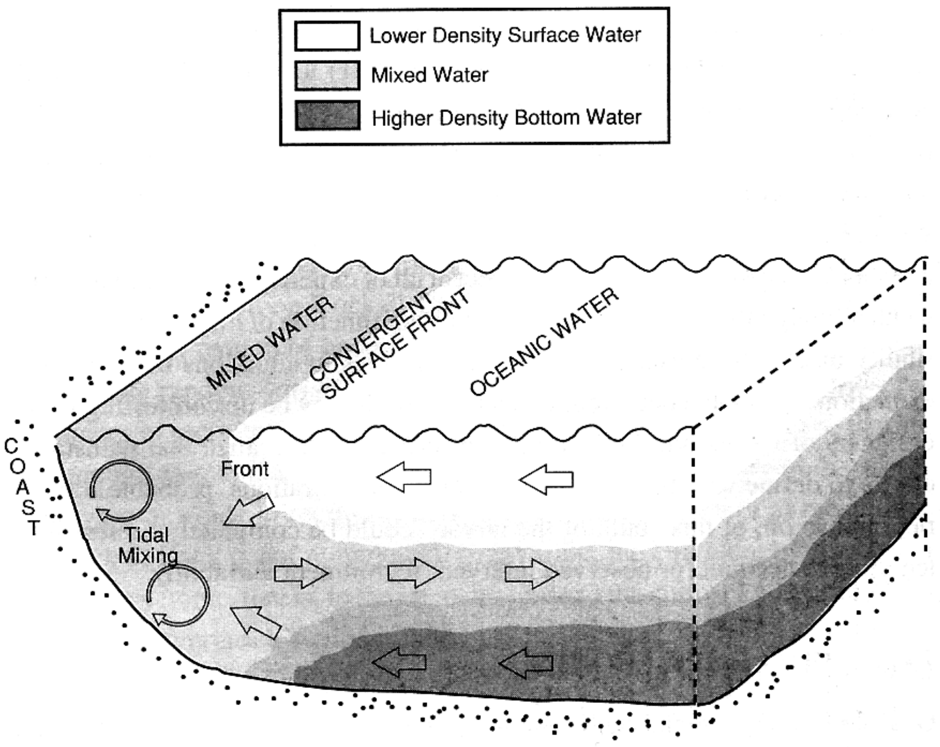
Estuarine Plume Fronts



- balance between friction and net pressure gradients from sloping sea surface and plume interface
- sharp salinity interface
- first studied Connecticut River (Garvine & Monk 1974; Garvine 1974)
- length scales of 1 km – 10's km



Shelf Fronts

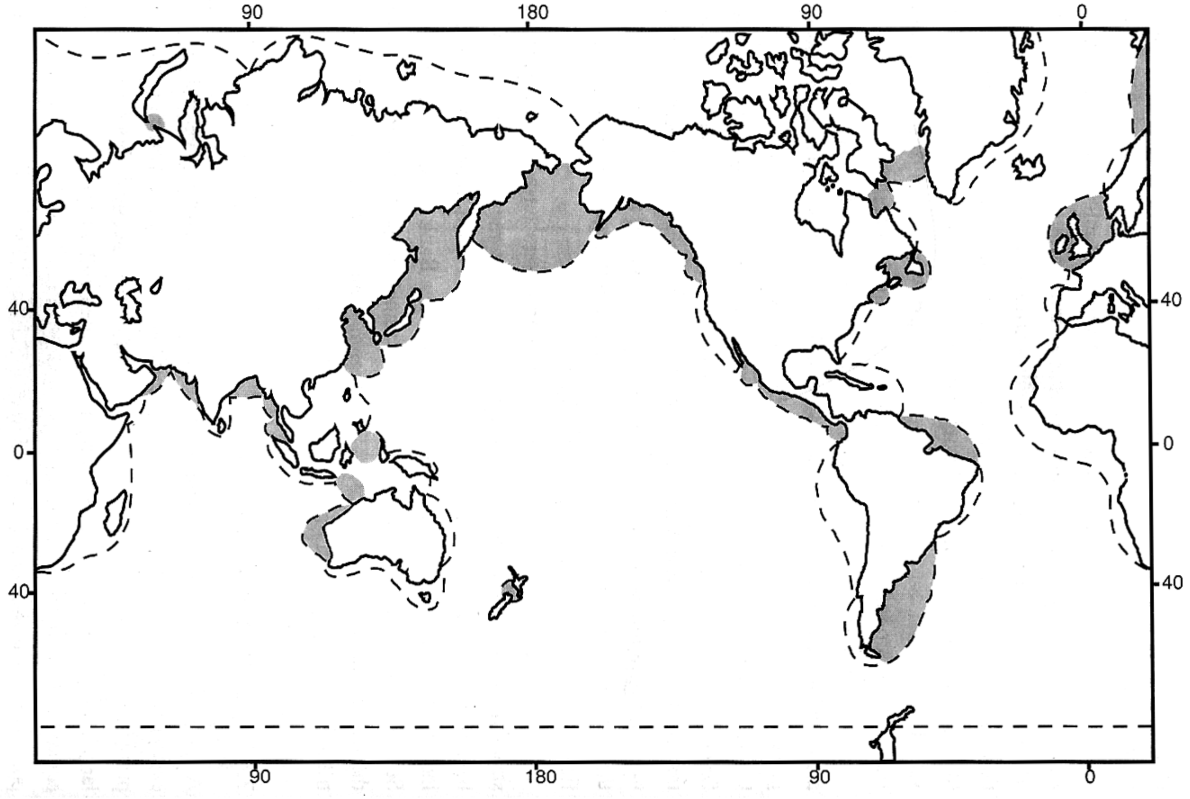


Bakun 1993

- over shelf, tidal mixing homogenizes water
- coastal surface water density < bottom water
- lighter surface offshore water to shoreward
- heavier bottom offshore water to shoreward
- intermediate shelf water to offshore

Shelf Fronts

What happens to the plankton?



Hunter & Sharp 1983

mobile: maintain position on inside front, near surface in nutrient enriched waters

passive: advected offshore?

Shelf Break Fronts

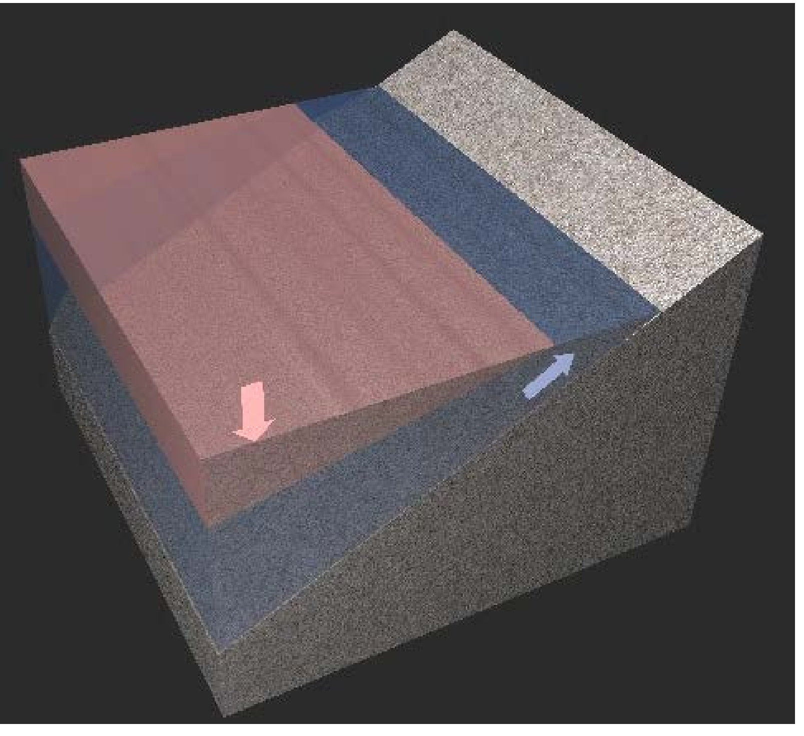
- occur near outer edge of continental shelf

- distinct density water masses: cold, low salinity shelf waters, warmer, saline slope waters

- in winter (i.e. mixing) resemble shallow sea tidal fronts (i.e. shelf fronts), front intersects bottom at shelf break

Are enhanced zooplankton levels due to convergence of organisms and nutrients or higher primary production?

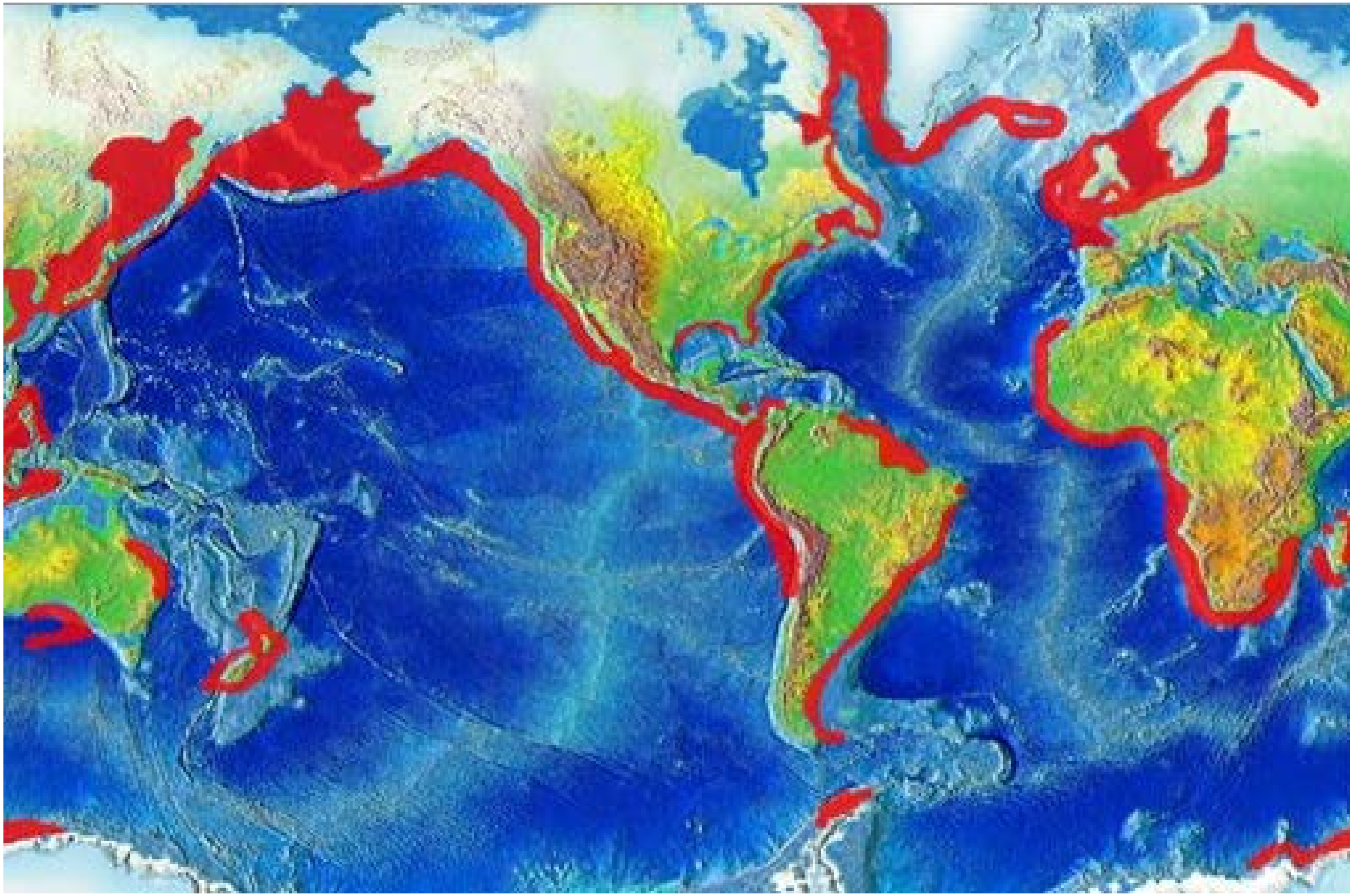
Upwelling Fronts



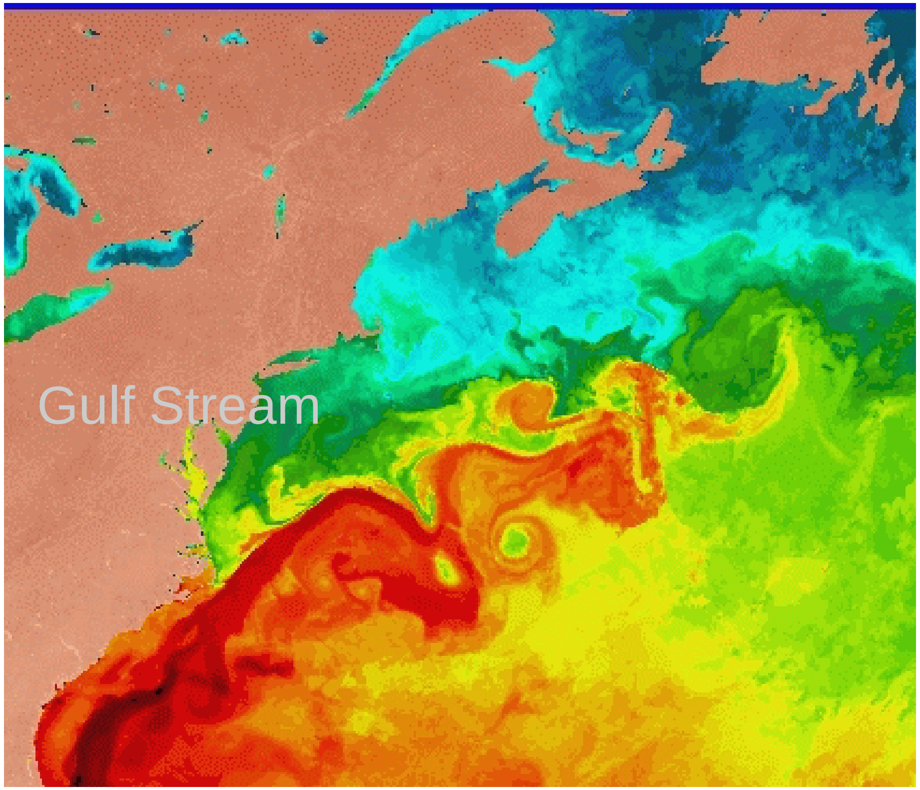
- pycnocline intersects sea surface in upwelling zone during favorable winds
- Example Oregon: 5 – 10 km offshore ~ Rossby radius
- inshore cool, dense, nutrient rich waters to euphotic zone to replace Ekman transported surface layer water
- winds relax, surface waters shift back inshore, front disappears

Rossby radius: length scale (horizontal), Coriolis force is balanced by pressure gradient force (i.e. buoyancy). Dependent on thermocline depth.

Coastal Upwelling Locations



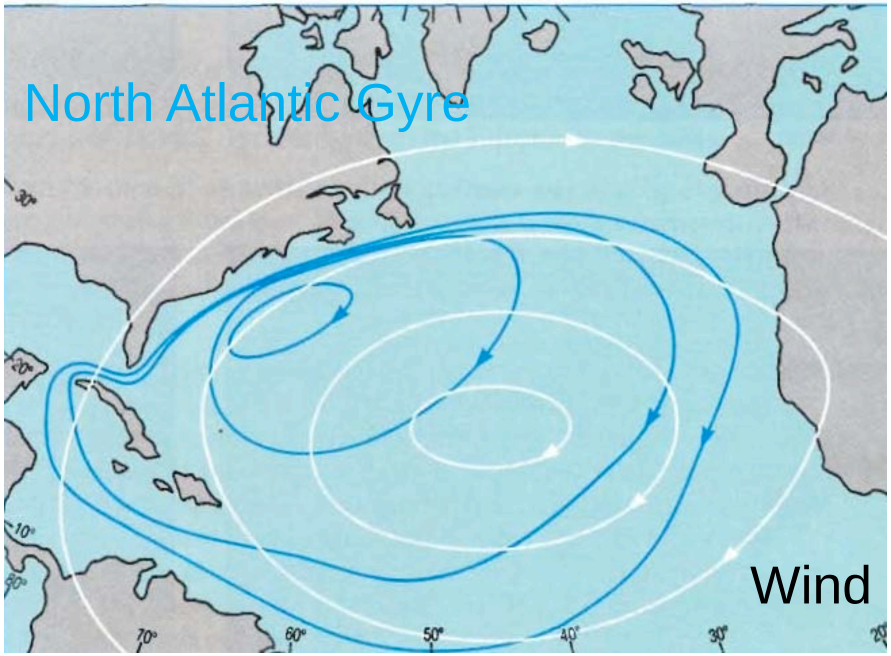
Gyres and Eddies



SST satellite image, from U. Miami RSMAS

- warm core and cold core eddies

- combinations of Eckman pumping and Sverdrup transport
- asymetrical flows, enhanced western boundary flow



World’s Ocean Gyres