SMS 303: Integrative Marine Sciences III

- Instructor: E. Boss, TA: A. Palacz

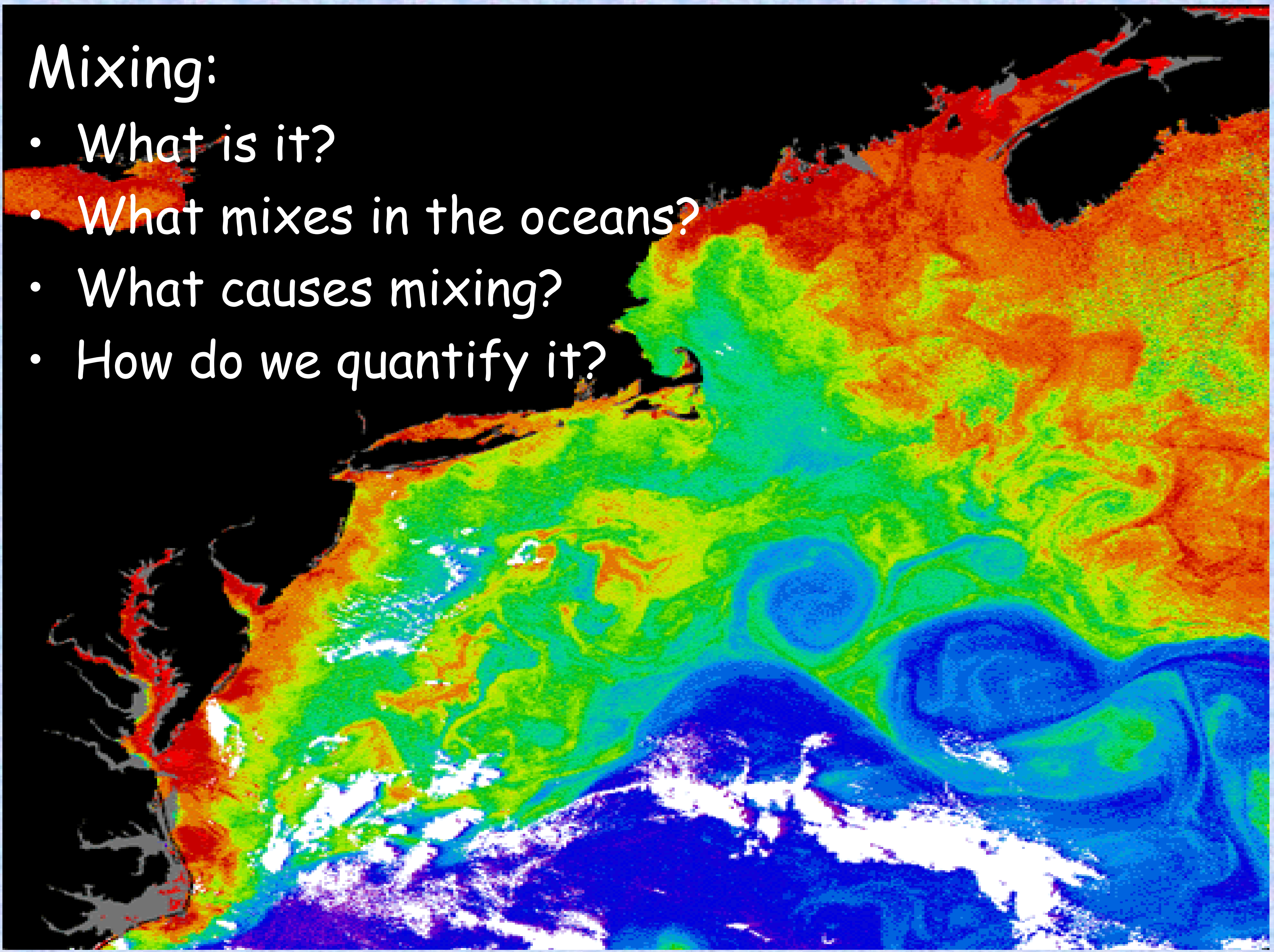
emmanuel.boss@maine.edu, 581-4378

- 5 weeks & topics: diffusion, mixing, Coriolis., waves and tides.

- Pre-class quiz.

Mixing:

- What is it?
- What mixes in the oceans?
- What causes mixing?
- How do we quantify it?



From last week, diffusion in 1-dimension:

$$\partial[C]/\partial t = -\partial F/\partial x = D\partial^2[C]/\partial x^2$$

How long will it take for a perfume to diffuse in the class by pure diffusion?

→ Diffusion coefficient of a typical organic molecule ~0.05 cm^2/sec in air

Room size – 5m

Dimensional analysis provide a time scale of = ?

Is this how long it really takes?

Why?

Stirring:

Increases the surface area of contact between coherent fluid parcels.

- Increases gradients by bringing contrasting fluids side by side.
- Reversible ← Movie.
- Stretch and fold (dough, candy) ← Movie.

Mixing:

Changing the properties of the fluid (at the molecules level).

- Erasing differences (how do we call differences in math?).

What mixes in the oceans?

Scalar quantities (passive and active).

Vector quantities – linear and angular momentum.

Stirring and mixing occur at different scales:

Stirring – energetic scales of the oceans.

Mixing – molecular scales.

How come the oceans are not well mixed?

What processes re-introduce gradients in properties to the ocean?

Stirring accelerates molecular mixing resulting in much faster mixing (e.g. stirring milk in your coffee).

How is this represented in models (parameterized) ?

In global circulation models that do not resolve the small eddies, the action of the eddies is parameterized using an ‘eddy diffusion coefficient’ and an ‘eddy diffusivity’ that is many orders of magnitude larger than molecular diffusion.

The value chosen is different for horizontal and vertical directions (why? Should one be larger than the other?).

A blob of fluid immersed in an ocean with eddies that are *much smaller*:

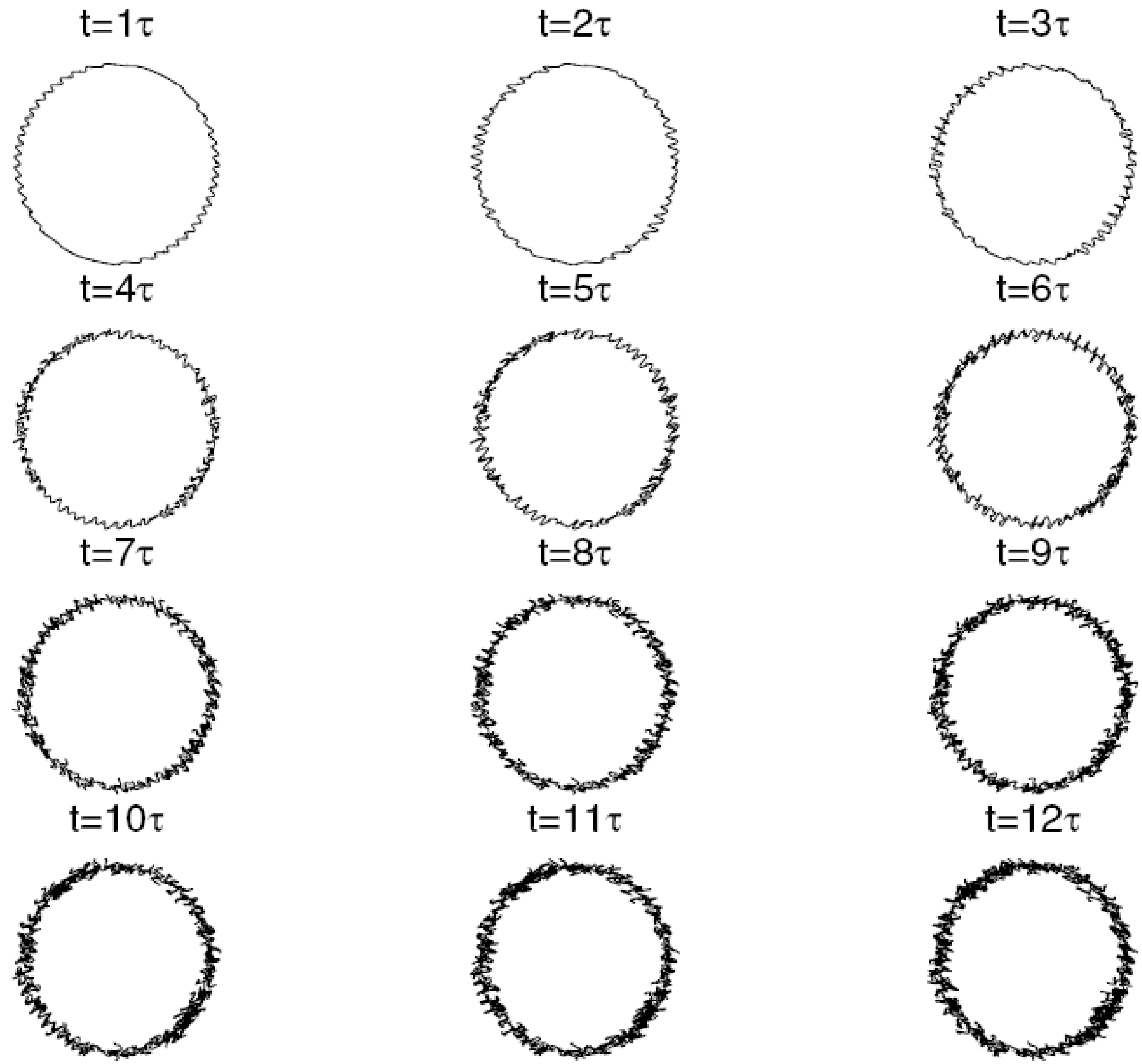


Figure 3: Stretching of a big blob $r \gg 1$, where r is the initial radius of the blob. The dotted circle representing the initial patch may not be visible beneath the wiggly boundary of the blob.

Bill Young @http://www-pord.ucsd.edu/~wryoung/GFD_Lect/eddyDiffChpt.pdf

A blob of fluid immersed in an ocean with eddies that are *much larger*:

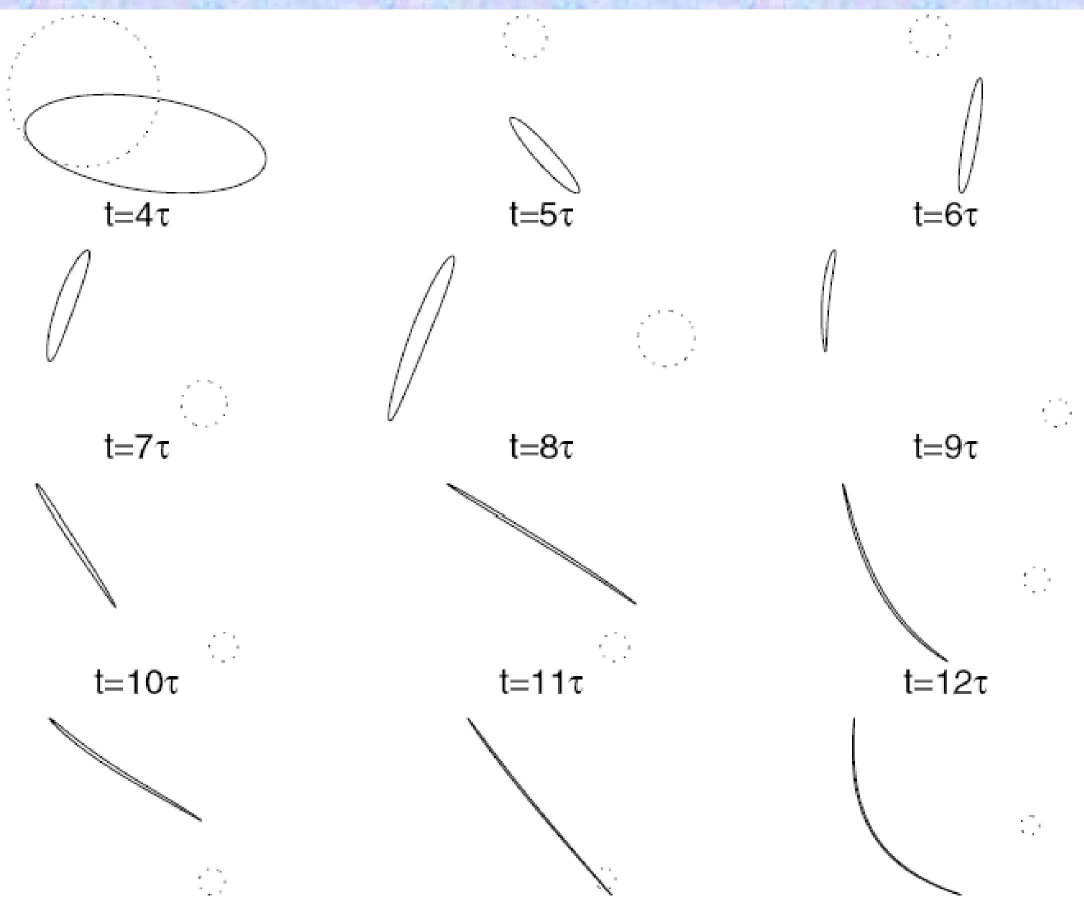


Figure 1: Stretching of a small spot, $r \ll 1$ where r is the initial radius of the spot, by a succession of random sinusoidal flows. The dotted circle is the initial spot.

Bill Young @http://www-pord.ucsd.edu/~wryoung/GFD_Lect/eddyDiffChpt.pdf

A blob of fluid immersed in an ocean with eddies that are of *similar* size:

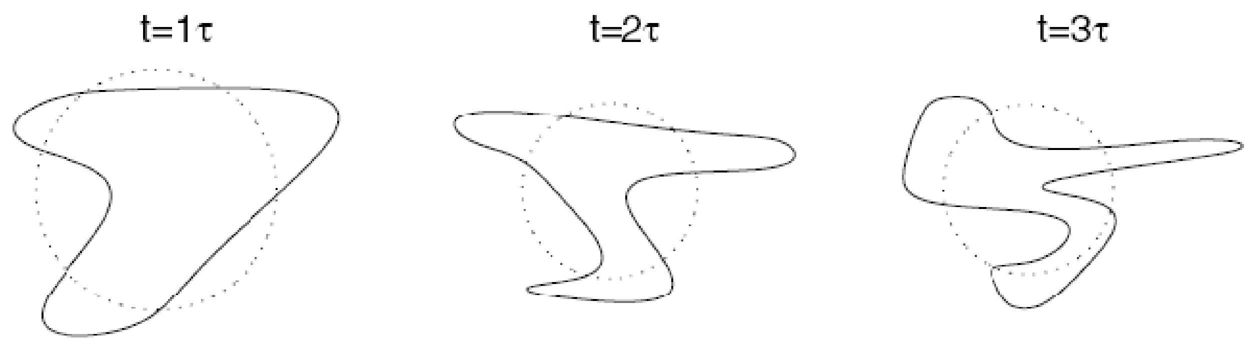
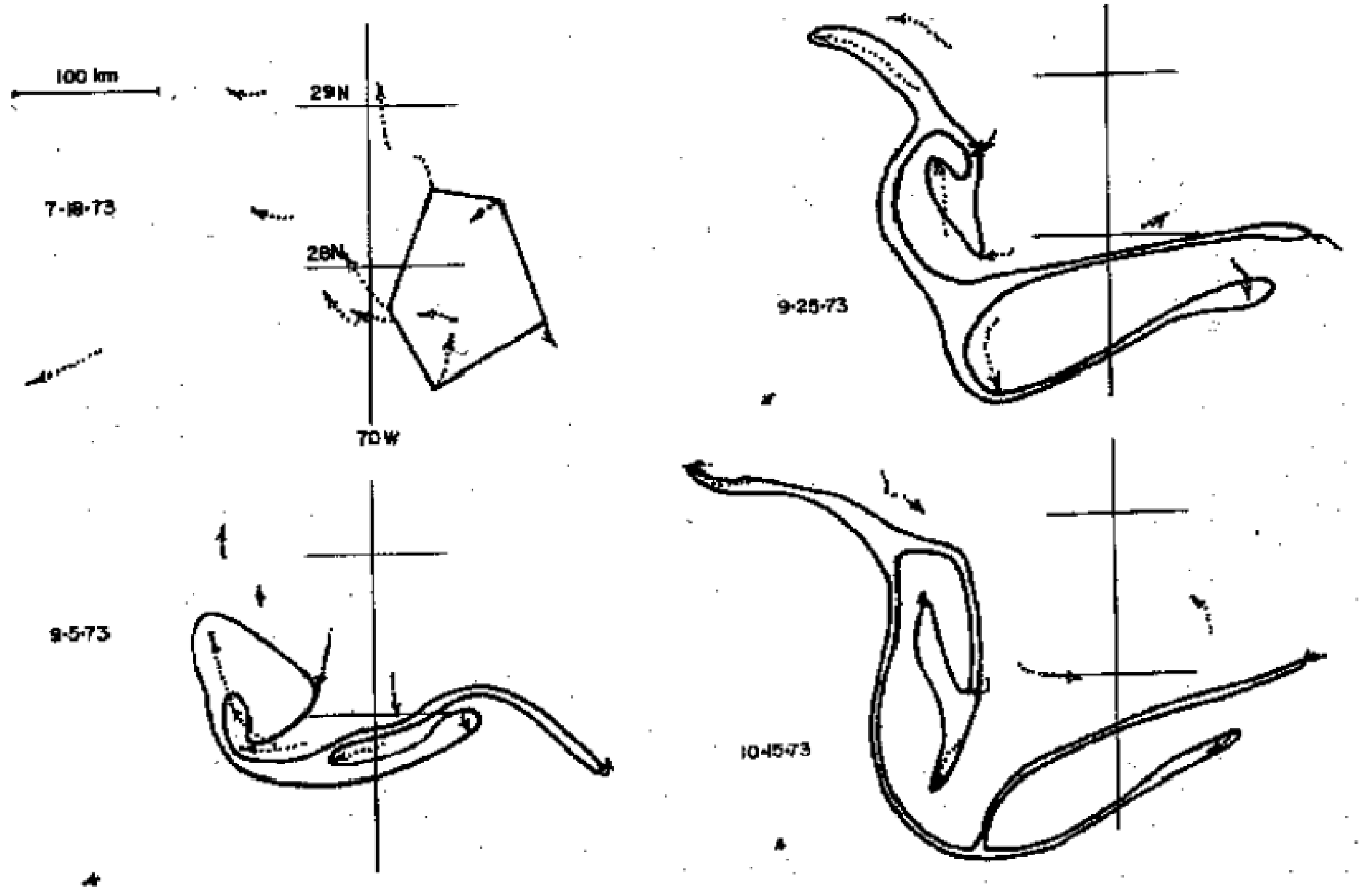


Figure 2: Stretching of a blob with $r = 1$, where r is the initial radius. The dotted circle is the initial patch.

Observation:

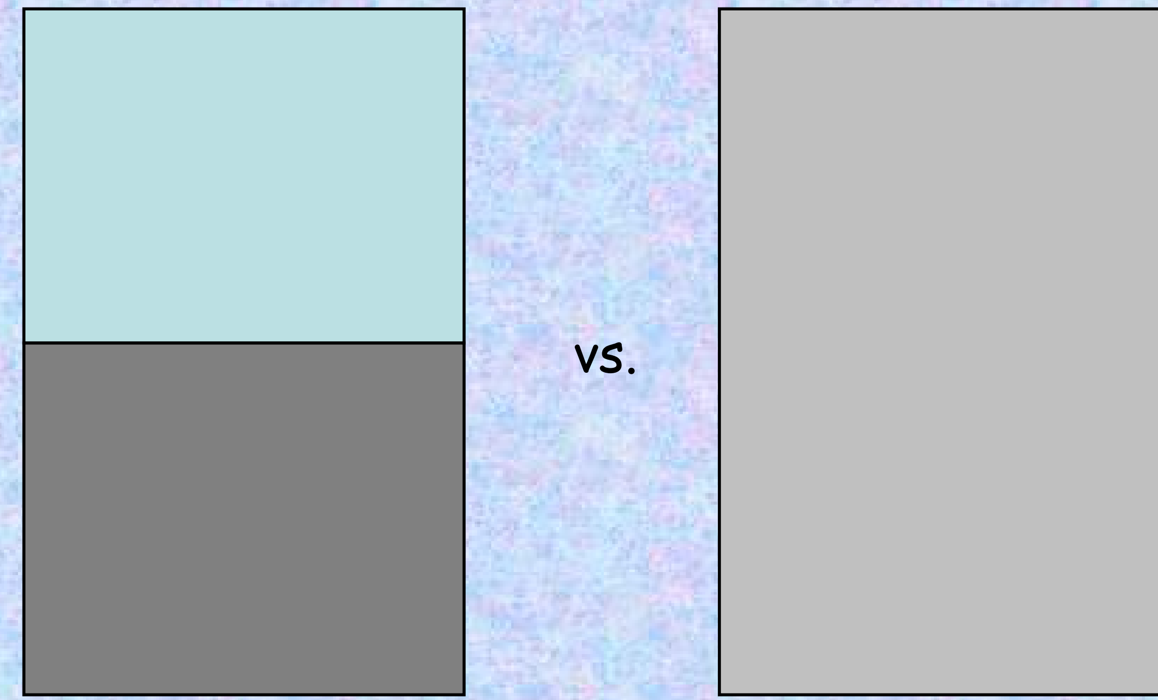


Distortion over a 3-month period of a polygon connecting 5 SOFAR floats.

Floats in an eddy field (Freeland, Rhines, and Rossby, 1975)

Mixing in a stratified fluid:

Why does it takes energy to mix a stratified fluid?



Which has a higher center of gravity?

Mixing in a stratified fluid:

Stratification inhibits mixing (requires work).

Vertical eddy diffusion ~ $(d\rho/dz)^{-1}$

Stratification, inhibit mixing (when >0)

The Richardson number:

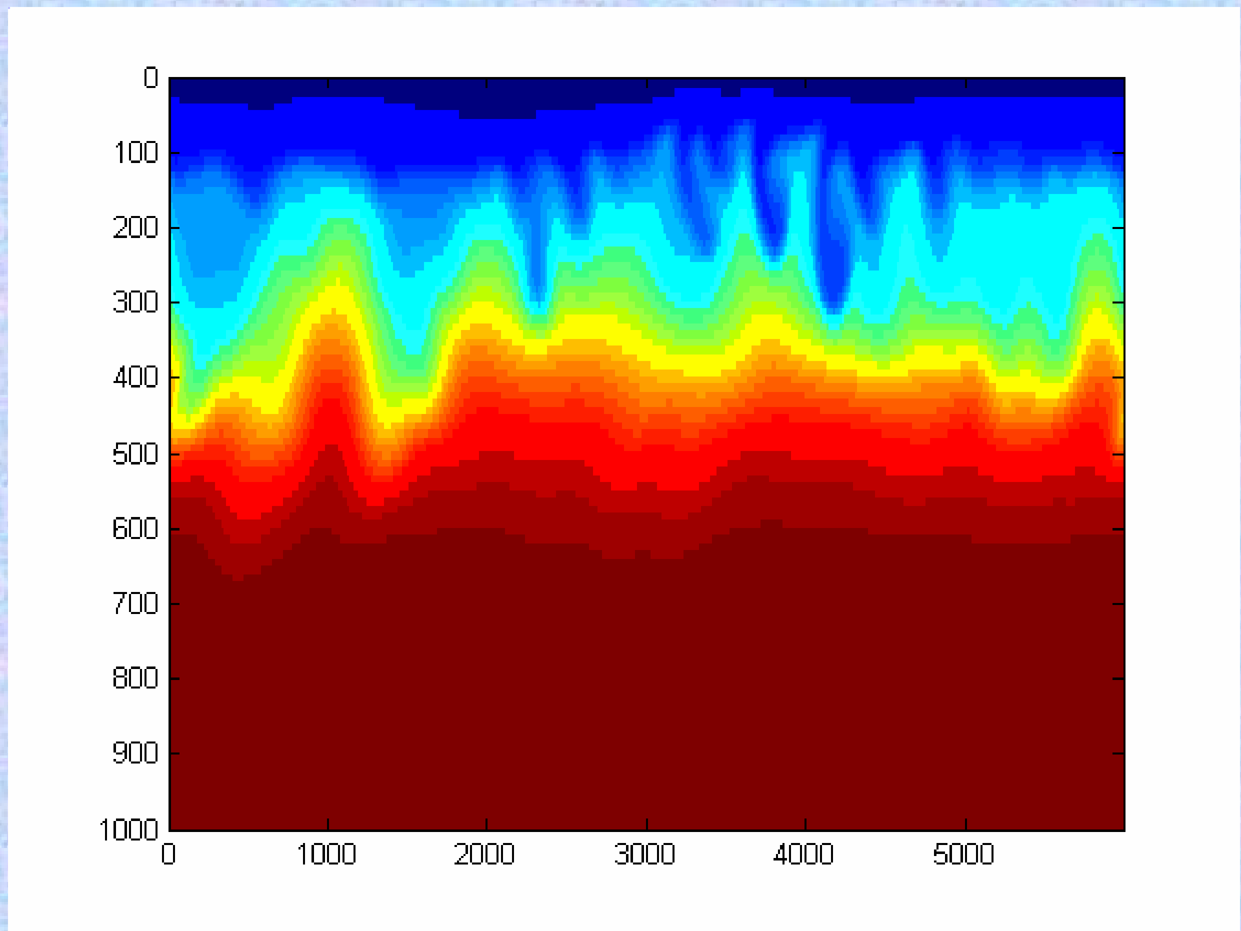
$$Ri = \frac{\dfrac{-g}{\rho}\dfrac{\partial \rho}{\partial z}}{\left(\dfrac{\partial u}{\partial z}\right)^2}$$

Shear, enhances mixing, trough instabilities

Mixing occurs when Ri<0.25.

What causes mixing in the oceans?

I. Haline and thermal convection (entrainment of water).

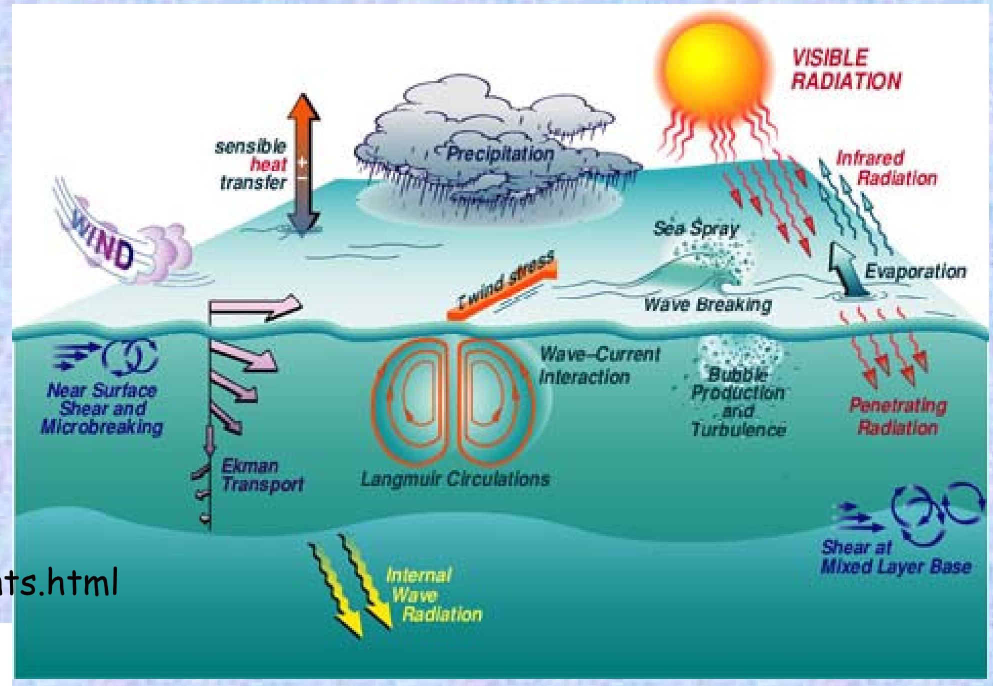


http://www.ifm.uni-hamburg.de/~wwwsh/aim.html

Occur under ice (why?), in lakes, during cold days and night, where deep water forms, at spreading centers etc'.

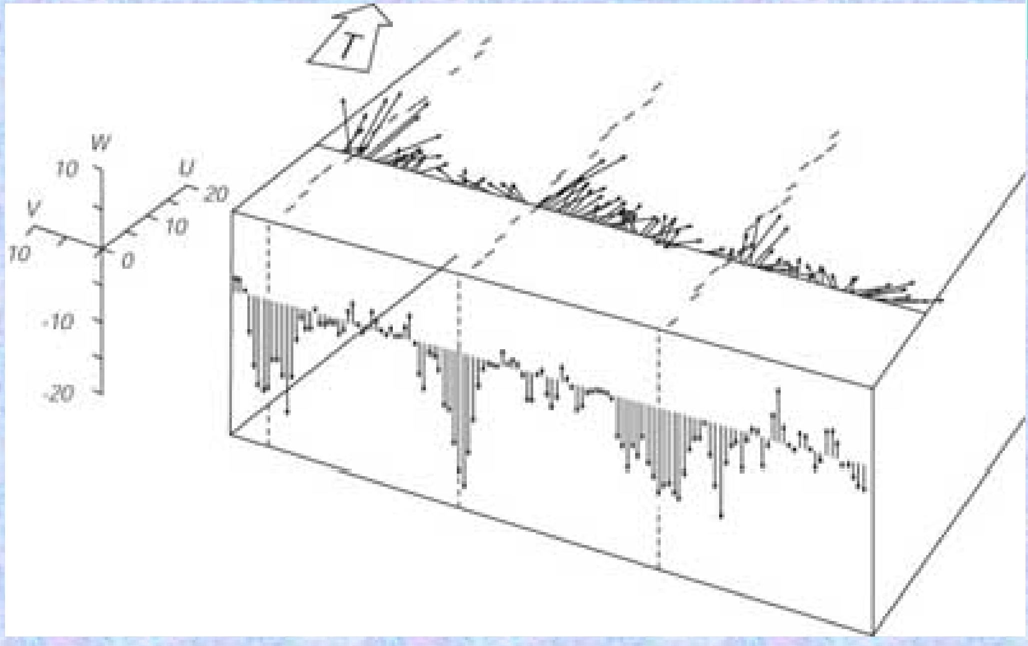
What causes mixing in the oceans?

II. Wind –Entrainment of fluid by Langmuir circulation.



http://www.hpl.umces.edu/~lzhong/mixed_layer/sml.htm

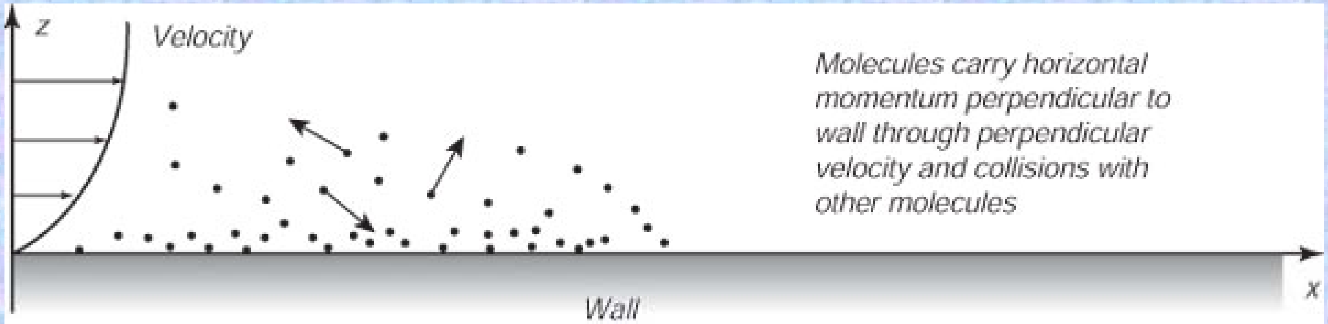
http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html



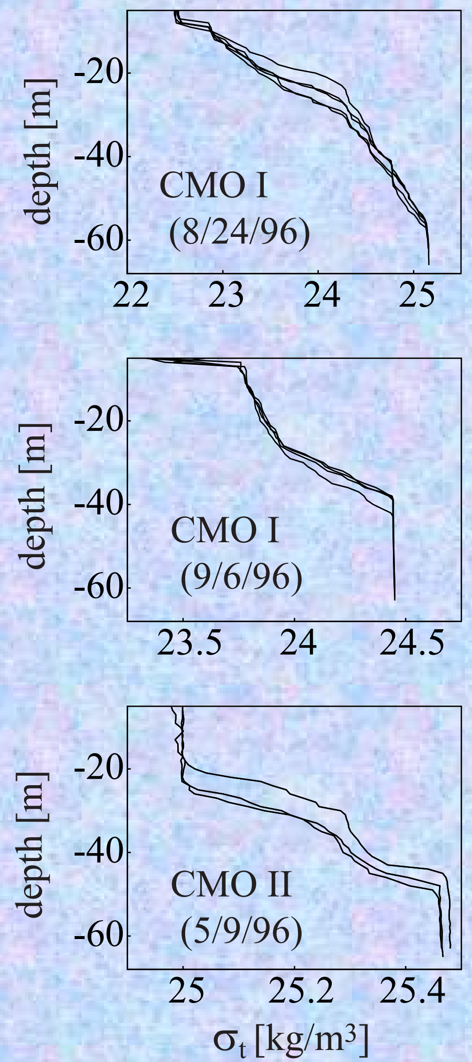
What causes mixing in the oceans?

III. Bottom stress:

bottom boudary layer (BBL)



http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html



Mixing near bottom on continental shelf.

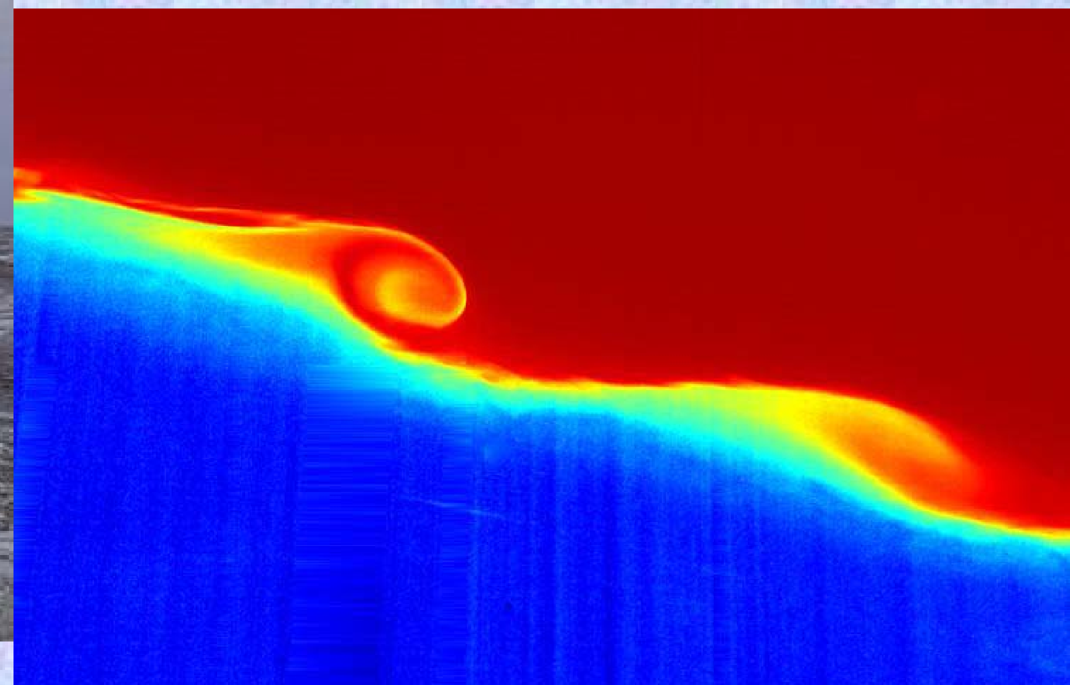
How would bottom roughness affect mixing?

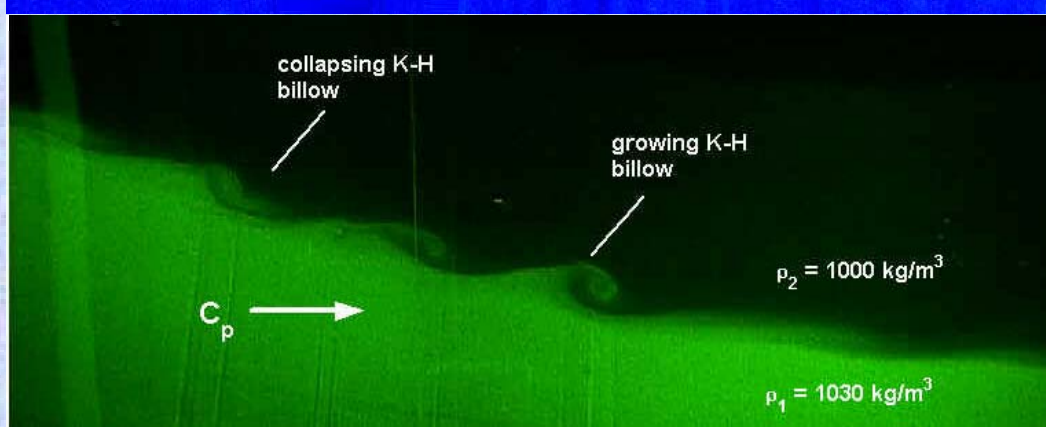
What causes mixing in the oceans?

IV. Breaking surface and internal waves.

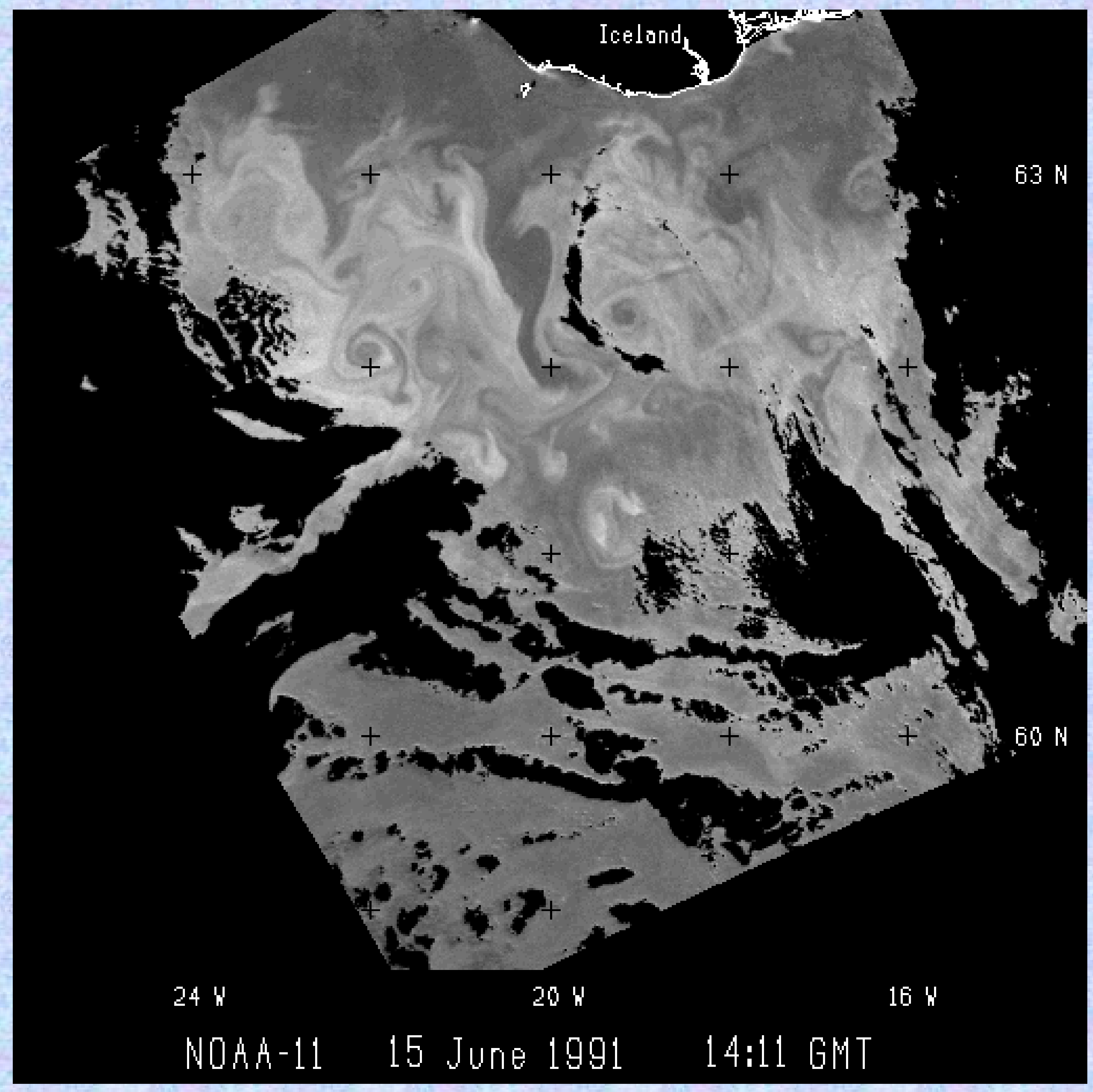
http://psc.apl.washington.edu/HLD/CBL/Teacher/Webcode/020905.jad8_007.jpg

http://fluid.stanford.edu/~carytroy/www/research/breakingwaves/breakingwaves.htm





V. Stirring by eddies:

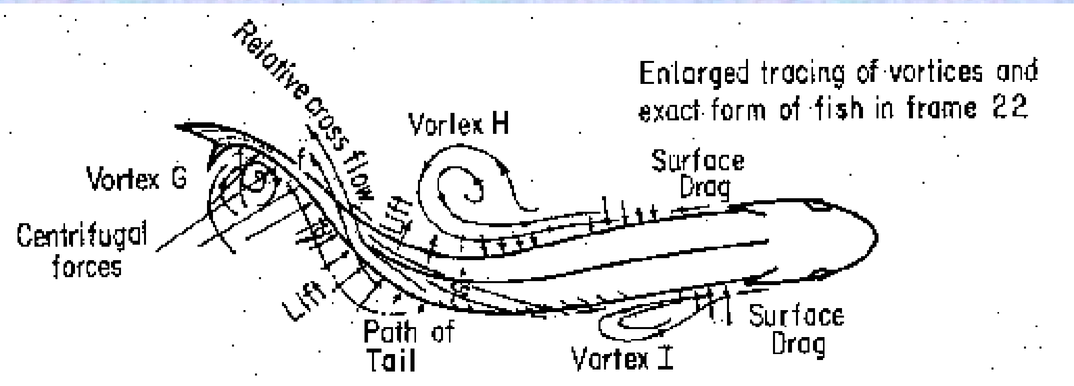


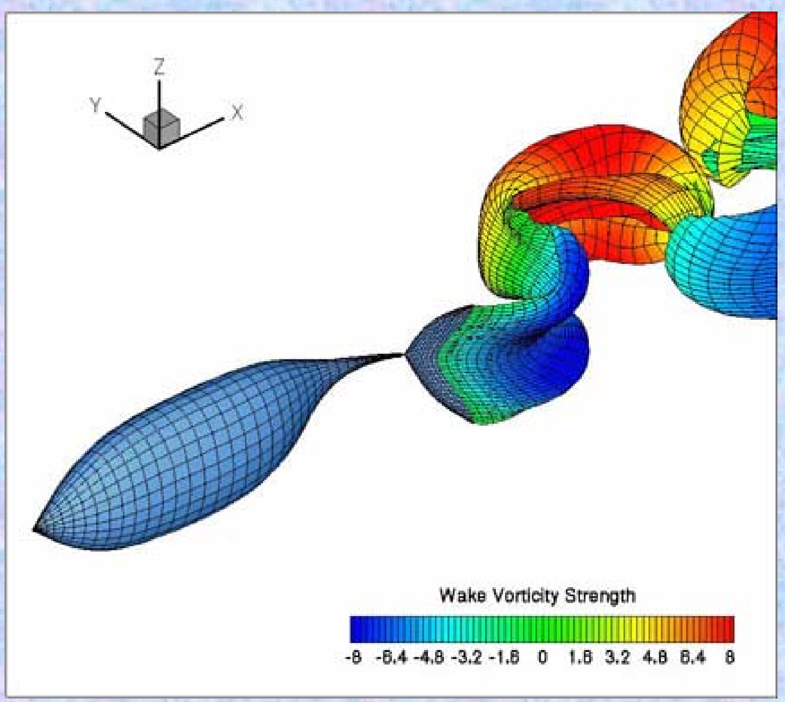
Data from Dundee Satellite Receiving Station

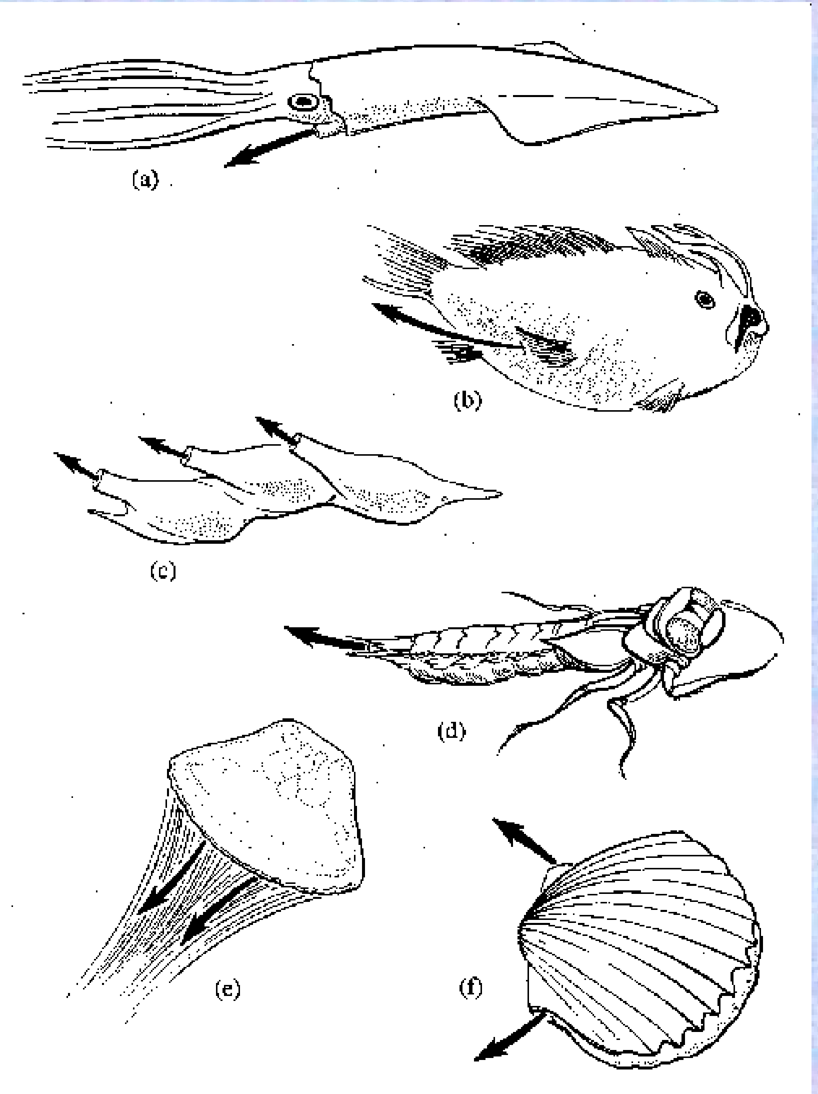
Processed by Steve Groom, RSDAS, PML

What causes mixing in the oceans?

VI. Biology.







Importance has been dismissed. Some think it contributes significantly to ocean mixing.

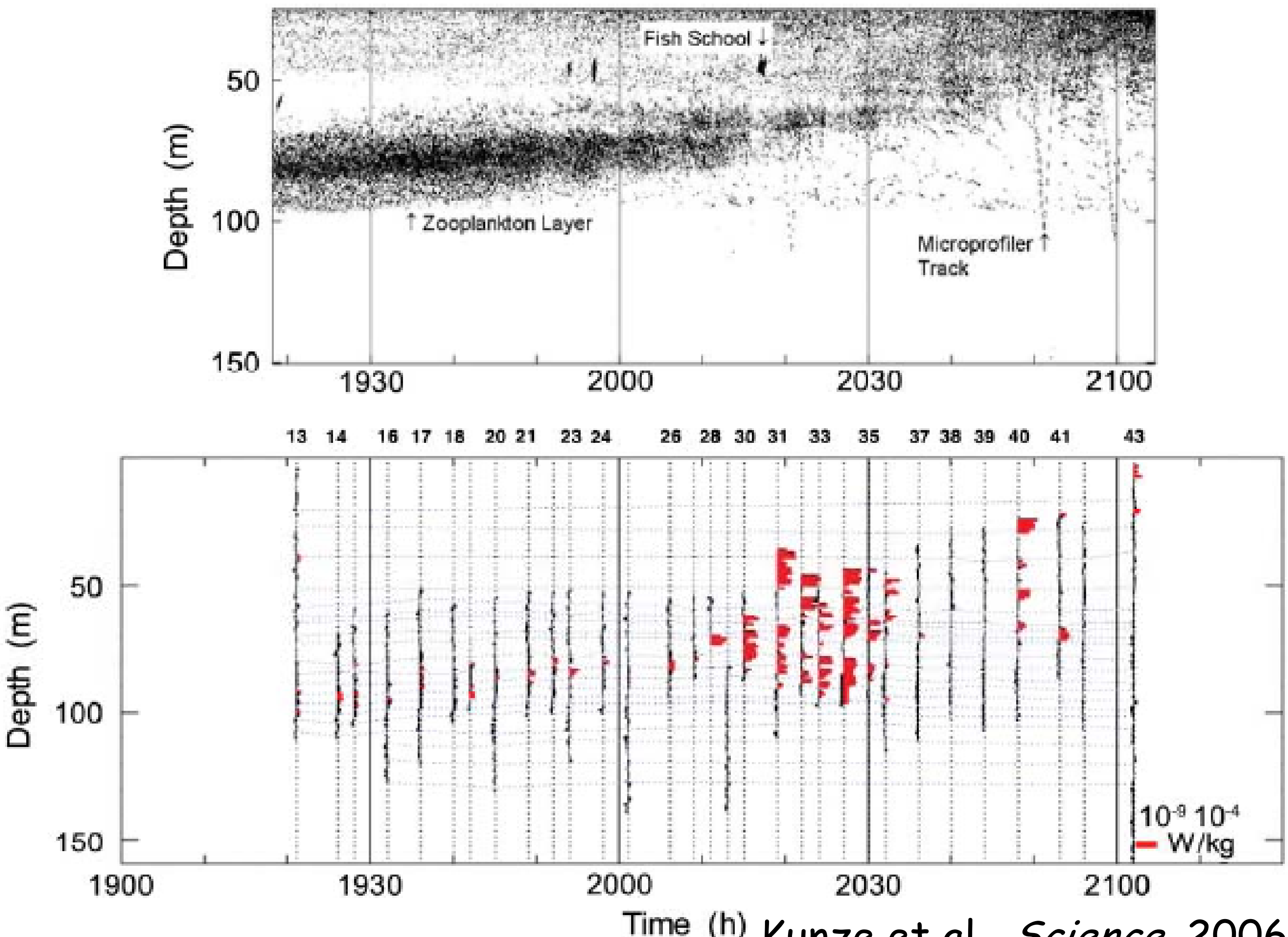
VI. Biology.

SCIENTIFIC AMERICAN.COM

September 21, 2006

Shrimpy Krill May Cause Big Ocean Mixing

Fig. 1. Profile time series in Saanich Inlet spanning about 100 min during dusk on 28 April 2005. (**Top**) Acoustic backscatter data from a 200-kHz echosounder reveals vertical migration of the backscatter layer. The lowering and raising of the vertical microstructure profiler is also evident for some profiles. (**Bottom**) Turbulent dissipation rate log(ε) (red, index lower right) with vertical dotted lines denoting profile times and horizontal dotted lines denoting salinity or density surfaces. For profiles 13 to 29, dissipation rates are on the order of 10^{-9} W kg^{-1}. For profiles 30 to 36, spanning 17 min, dissipation rates are two to four orders of magnitude higher before falling back to background levels of about 10^{-9} W kg^{-1} for the remainder of the time series.

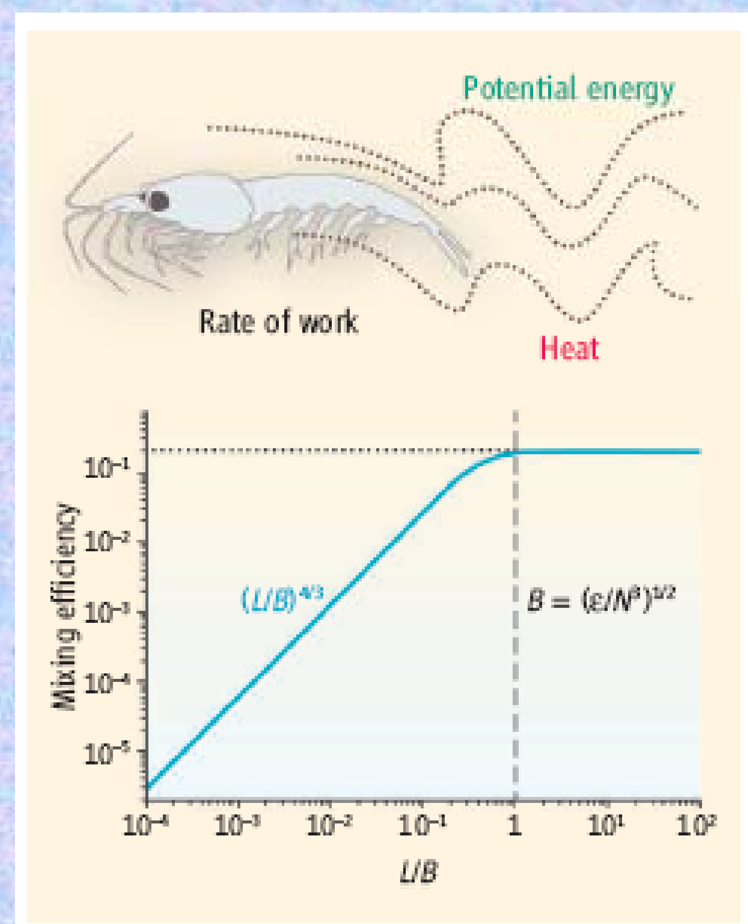


Kunze et al., *Science*, 2006

VI. Biology.

September 21, 2006

Shrimpy Krill May Cause Big Ocean Mixing



Visser, *Science*, 2007

Small organisms do a lot of work swimming in water (quantified by ε, the energy dissipation rate).

Work will cause mixing if done on scales in which the water is stratified (quantified by N^2 the buoyancy frequency).

This provides a length scale: $B= (\varepsilon N^3)^{1/2}$

For mixing to be efficient the object size, L, has to be of the same size or larger than B.

Mixing and the oceanic thermocline:

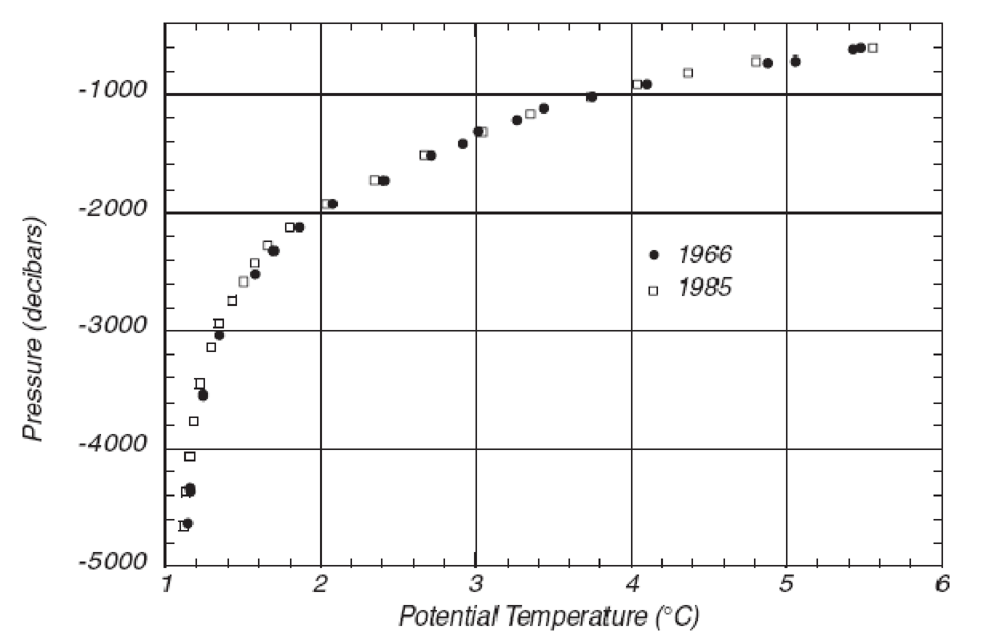
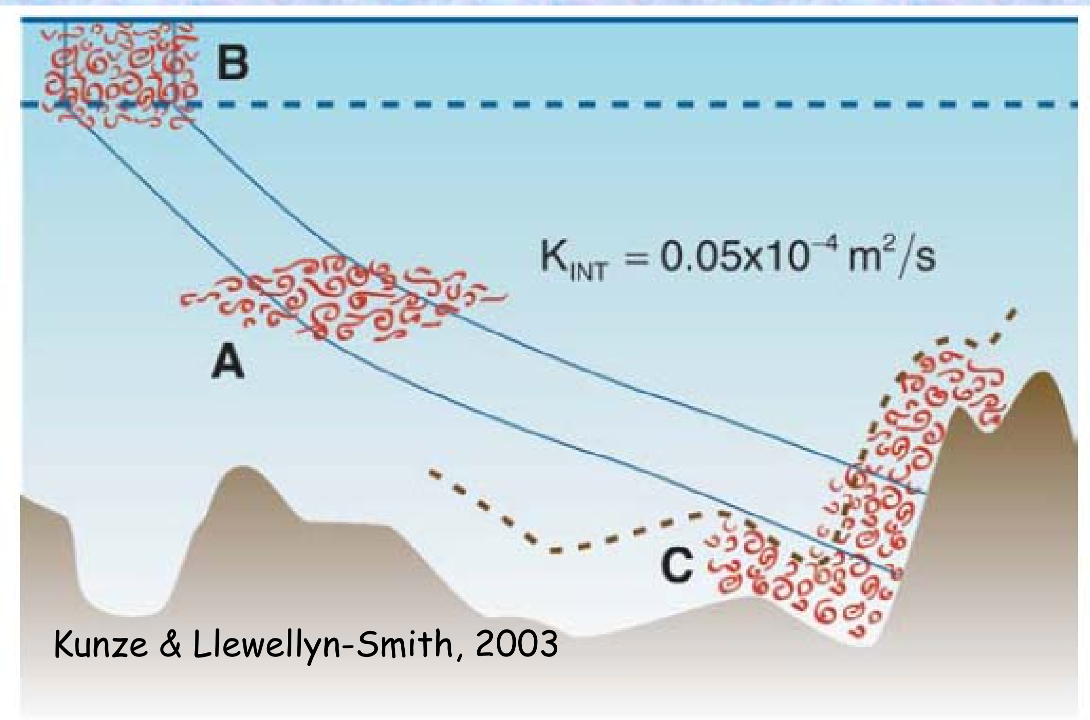


Figure 8.8 Potential temperature measured as a function of depth (pressure) near 24.7°N, 161.4°W in the central North Pacific by the *Yaquina* in 1966 (•), and by the *Thompson* in 1985 (□). Data from *Atlas of Ocean Sections* produced by Swift, Rhines, and Schlitzer.

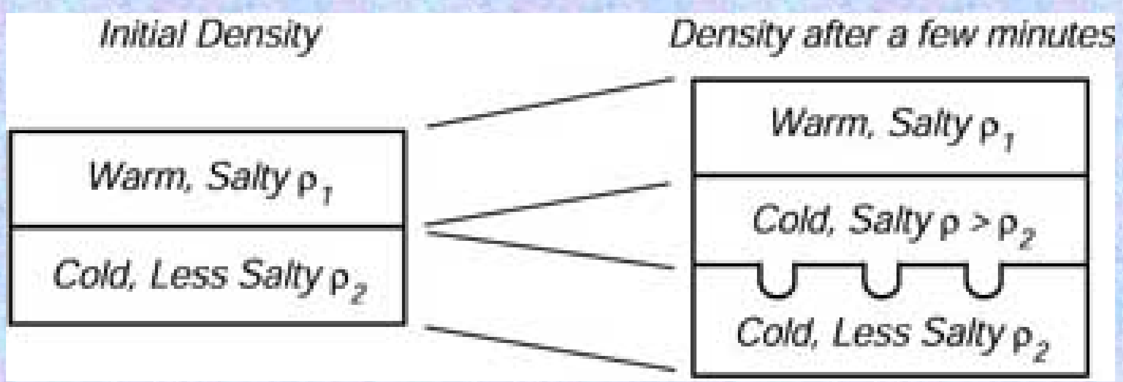
If we equate turbulent diffusion with upward advection we need an eddy diffusivity which is 20 times higher than observed in the open NA ocean.



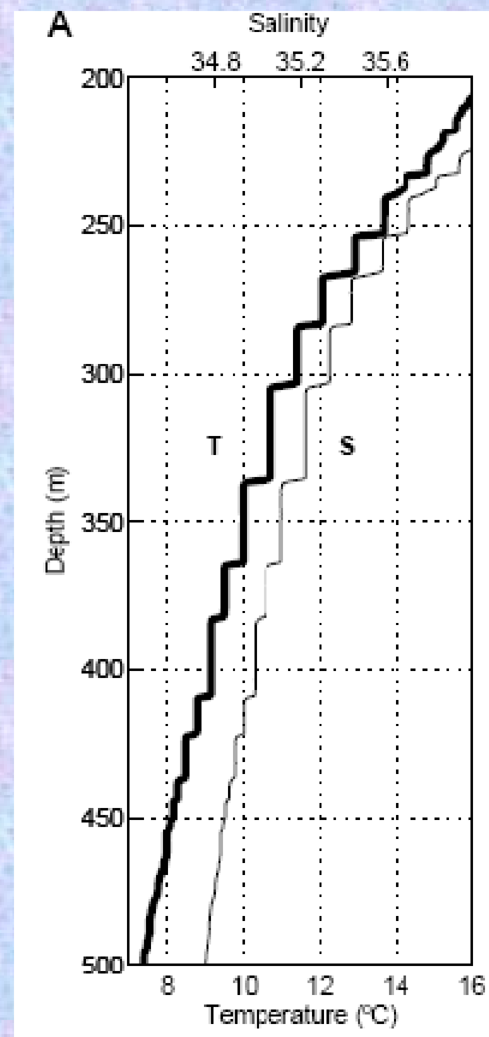
Alternatives are either surface-enhanced mixing where density surfaces outcrop at polar latitudes (B) or bottom enhanced mixing over rough topography (C), the products of which then stir along density surfaces to fill the interior.

What causes mixing in the oceans?

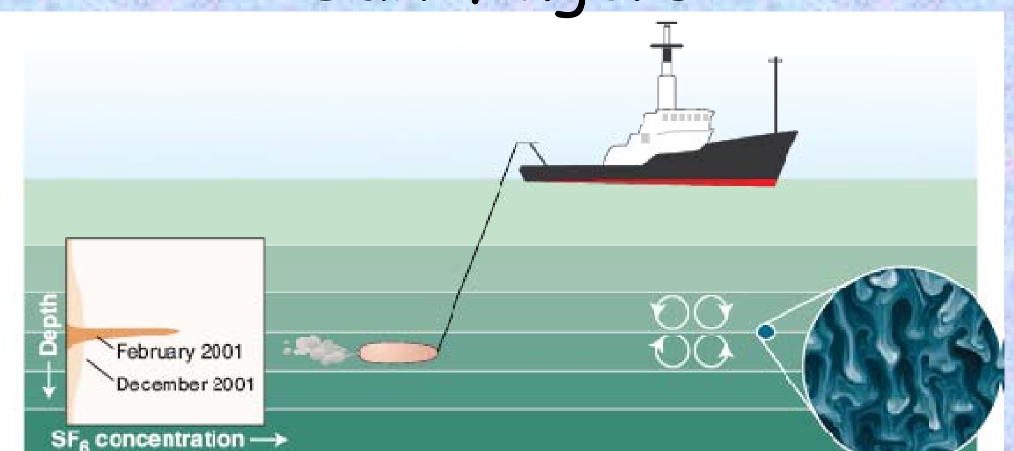
VII. Double diffusion- $D_{temperature} = 100 \times D_{salt}$.



http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html



Salt fingers



Staircase mixing in the ocean. In early 2001, 175 kg of inert SF_6 were released into a "thermohaline staircase" in the western tropical Atlantic. Subsequent vertical dispersion of this tracer (**inset, bottom left**), measured 10 months later, revealed the extent of mixing by salt fingers in the thin interfaces (**inset, bottom right**) and by convection within the thicker layers. The mixing rate, which applies to salinity, was approximately double that of heat.

Enhanced Diapycnal Mixing by Salt Fingers in the Thermocline of the Tropical Atlantic

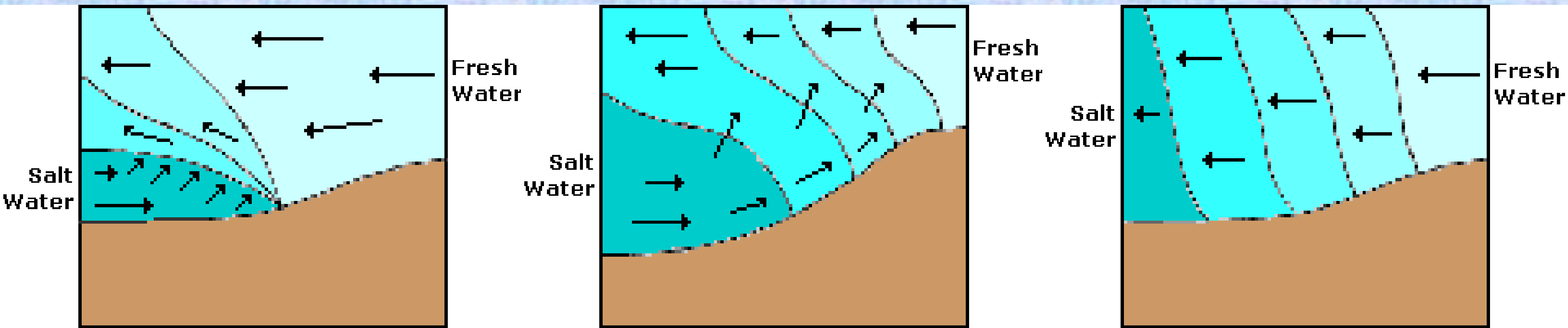
R. W. Schmitt,* J. R. Ledwell, E. T. Montgomery, K. L. Polzin, J. M. Toole

SCIENCE VOL 308 29 APRIL 2005

Vertical eddy diffusion~ 0.9×10^{-4} m^2/s

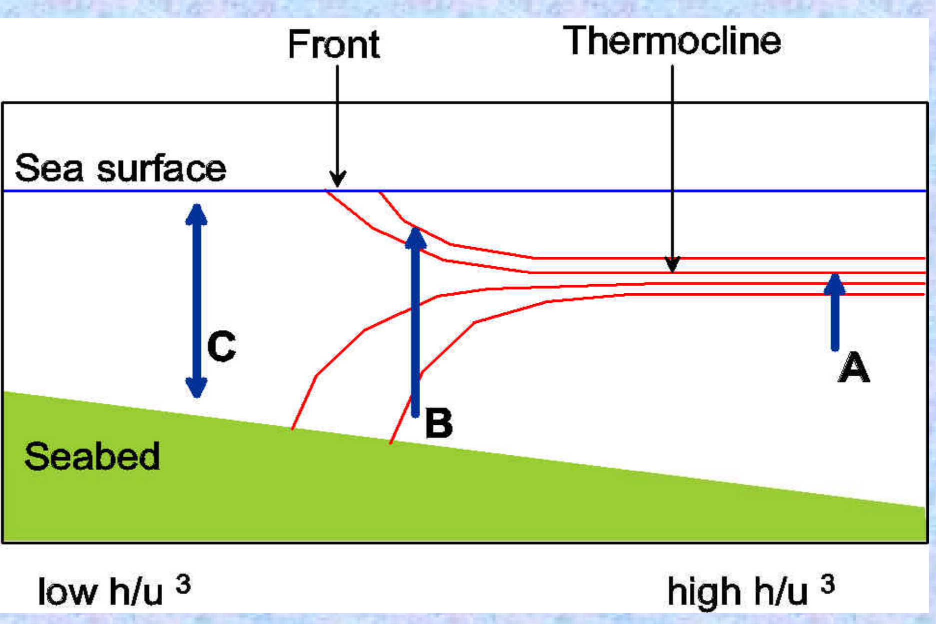
VIII. Mixing by tides (combination of bottom stress and lateral gradients):

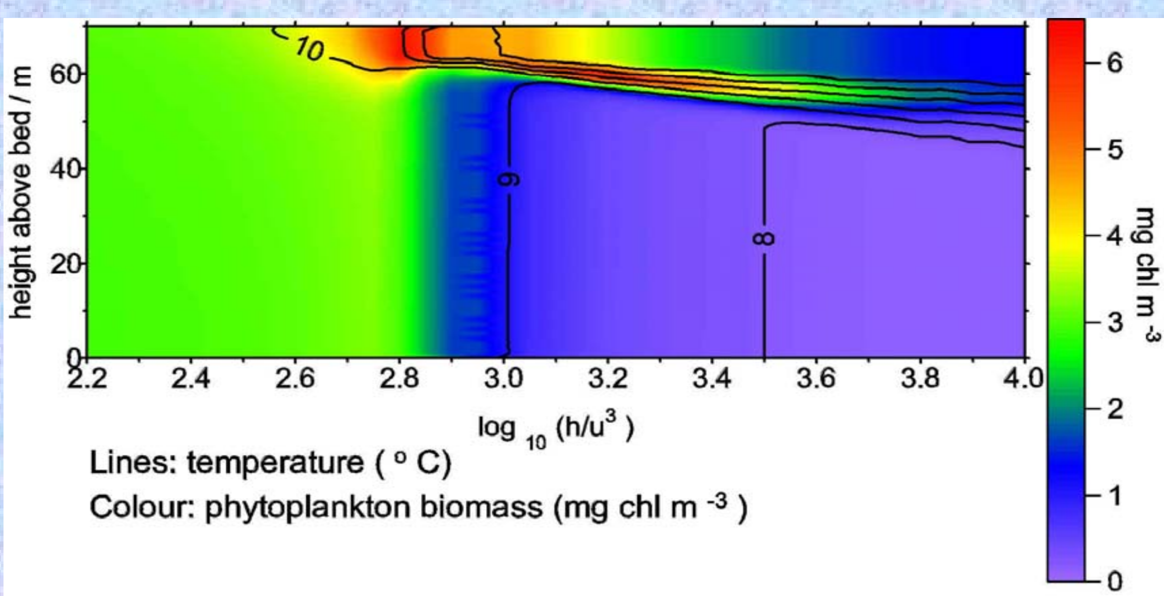
Can dominate distributions of properties in estuaries and shallow seas:



http://omp.gso.uri.edu/doee/science/descript/esttype2.htm

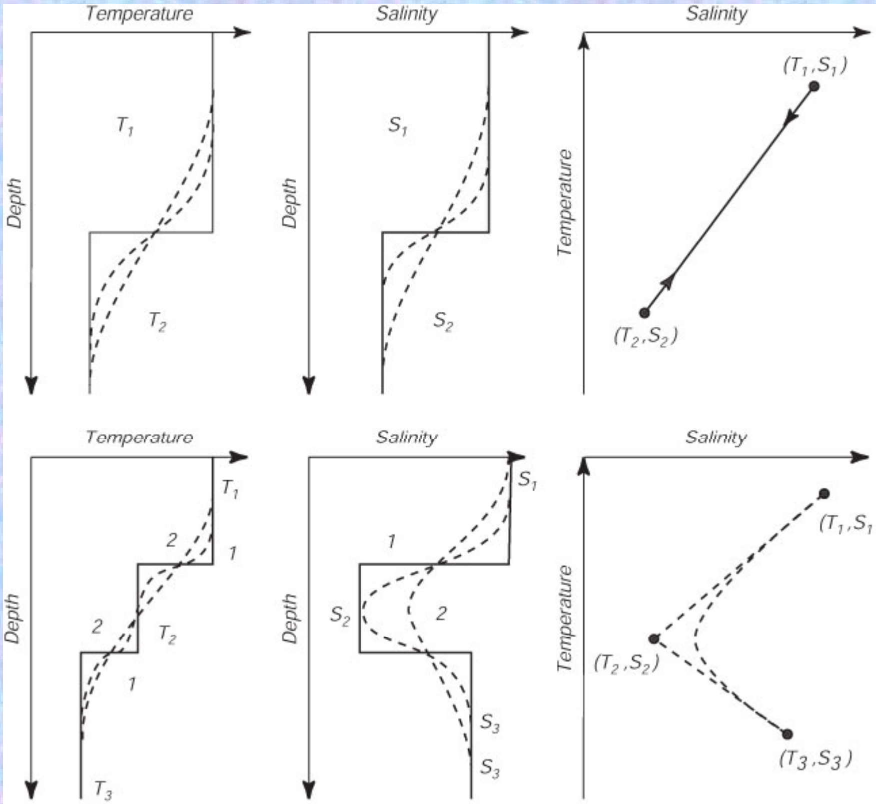
Can dominate the distribution of properties in shallow shelves:



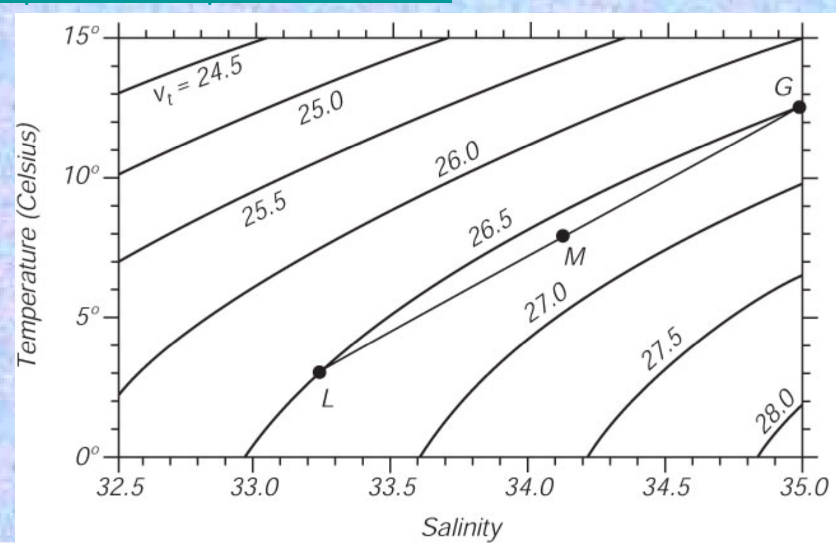


http://www.soes.soton.ac.uk/staff/js/phyto_1d.html

T-S diagrams and mixing



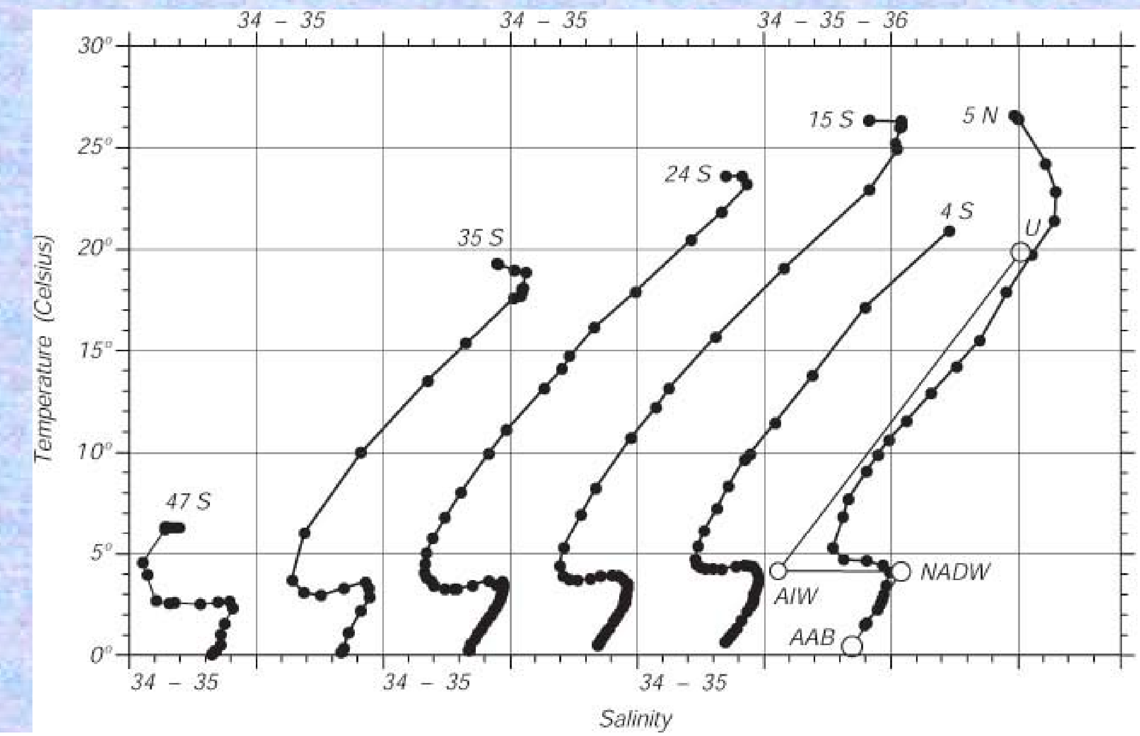
http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/chapter13_03.htm



Temperature and salinity mix linearly (in proportion to the relative amount of water).

Need to use potential temperature (not affected by pressure).

Nonlinear equation of state result in strange behavior.



Summary:

What is mixing? How does it differ from stirring?

What properties mix in the oceans?

What causes mixing in the ocean?

How do we recognize when mixing occurs?