SMS 303: Integrative Marine Sciences III

- Instructor: E. Boss, TA: L. Brothers

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- 4 weeks & topics: waves, tides, mixing and Coriollis.

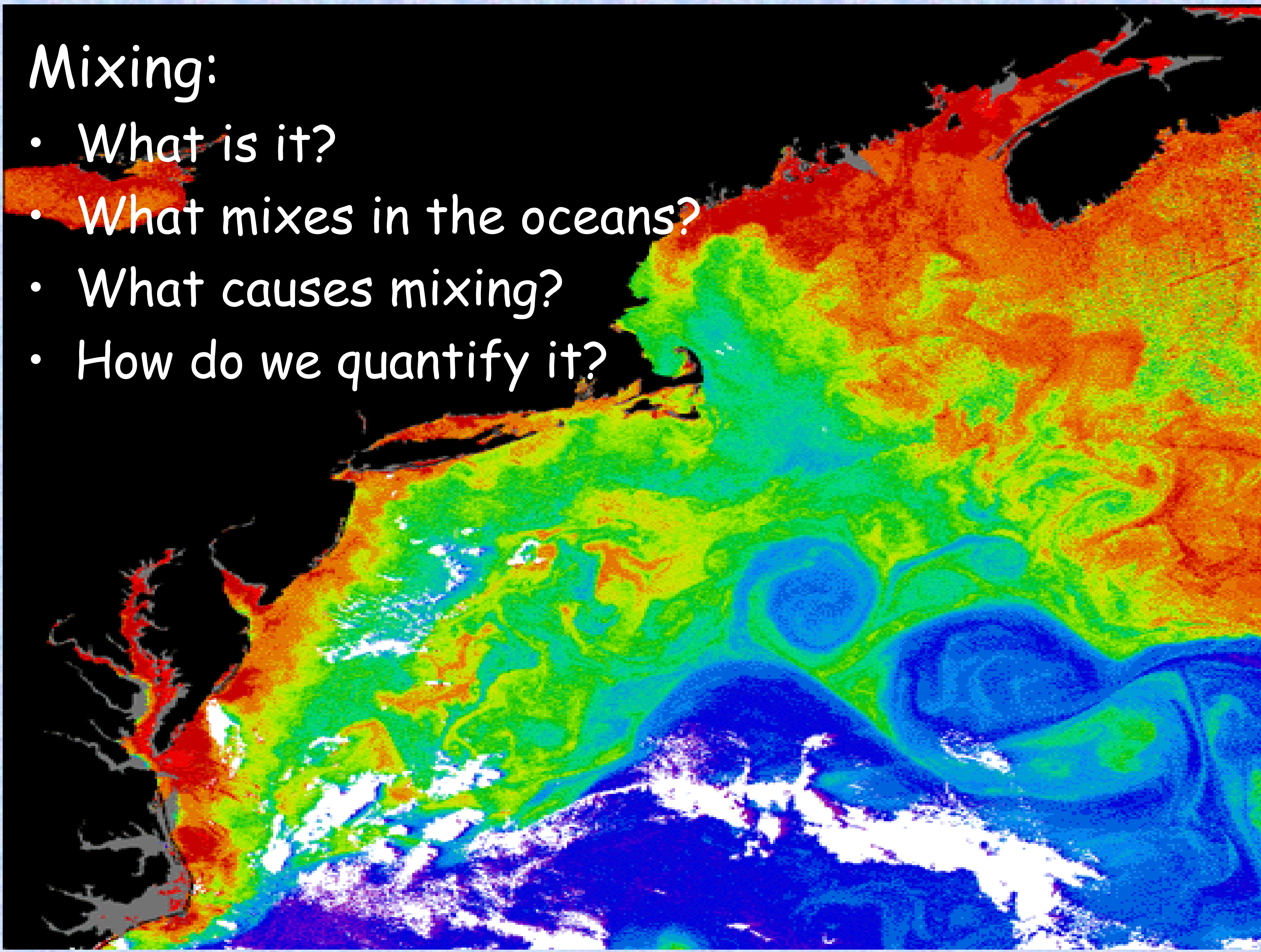
Change in plan – Coriollis moved to the last week of semester to accommodate a colleague that will be out of town.

- Expectations: participation, question asking, and homework (can be done in group, handed in individually)

- www.marine.maine.edu/~eboss/classes

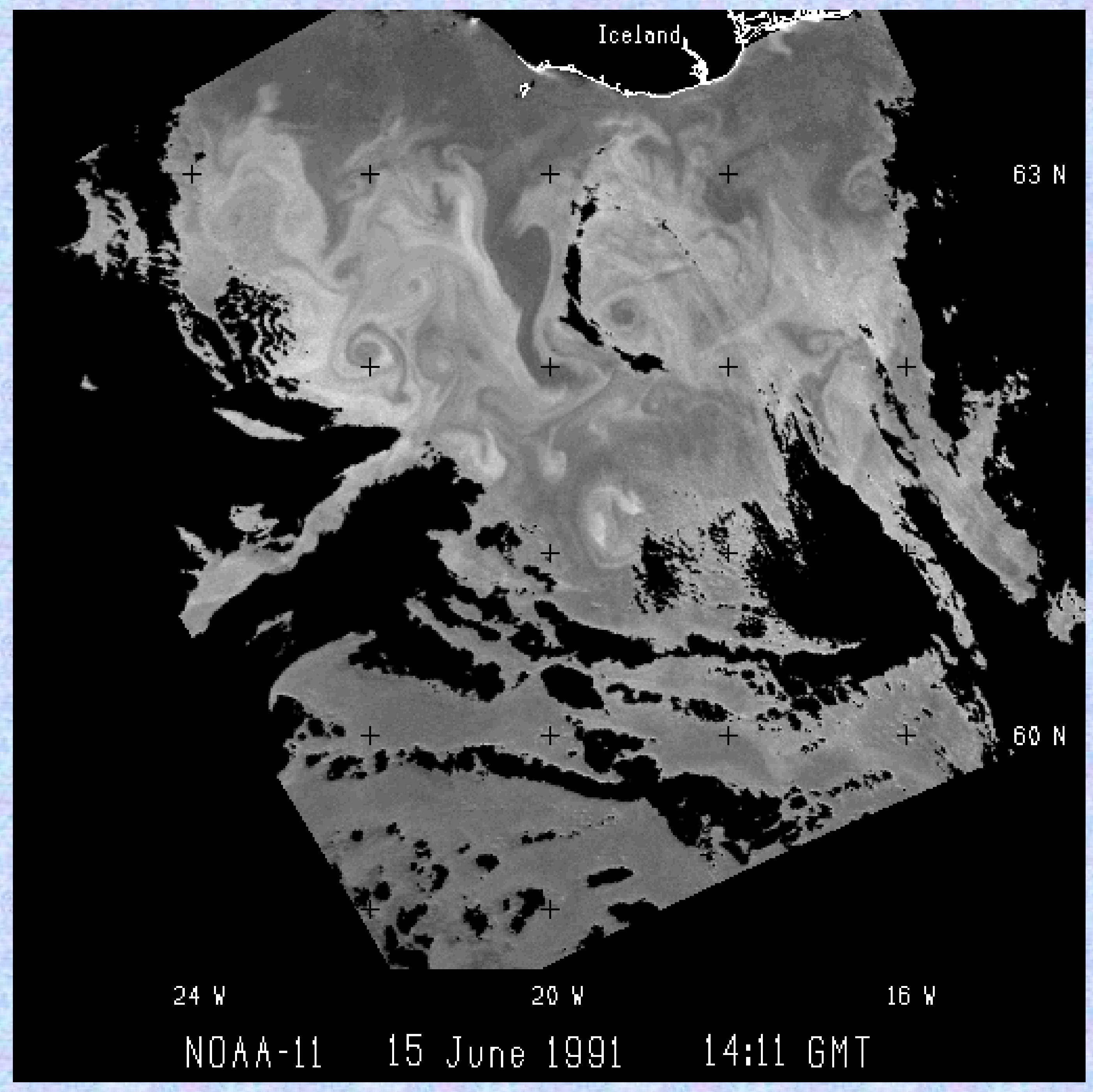
Mixing:

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



Data from Dundee Satellite Receiving Station

Processed by Steve Groom, RSDAS, PML



Mixing in a homogeneous fluid:

Fick's and Fourier's laws – down gradient flux of material and heat.

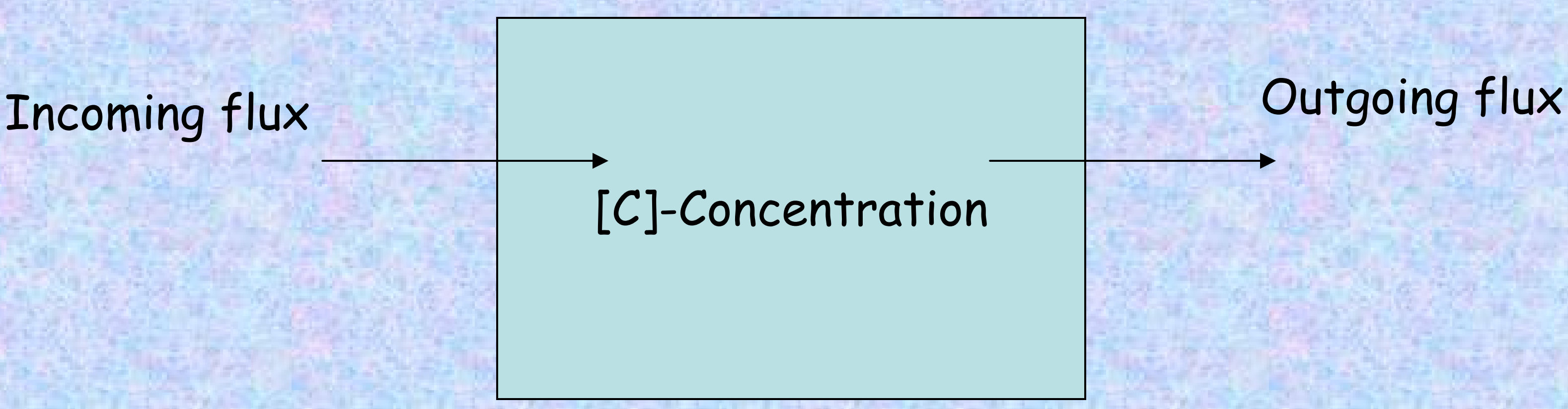
Friction – down gradient flux of momentum.

flux = -diffusion coefficient x gradient {e.g. [moles/s/m^2]}

In 1-dimension: $F=-Dd[C]/dx$

What are the units of the diffusion coefficient?

Same units (not value) for momentum, temperature and scalars.



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 = ?

Molecular origin of diffusion and viscosity:

Diffusivity of matter depends on:
Temperature, Size of molecules, viscosity of media.

Einstein: Diffusion is the macro scale realization of random motions (called Brownian motion) in the molecular scale.

D=constant x Temperature/{radius of molecules x medium's viscosity}

Simulation: http://www.scienceisart.com/A_Diffus/Jav1_2.html

Thermal diffusion, is the transfer of kinetic energy of molecular vibrations.

Viscosity, the diffusion of momentum, works much like billiard balls that transfer momentum to each other. The boundaries of the fluid are the sources/sinks for momentum.

Stirring:
Increases the surface area of contact between a coherent fluid parcels.

- Increases gradients by bringing contrasting fluids side by side.

- Reversible.

- Stretch and fold (dough).

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 (Which is larger?).

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

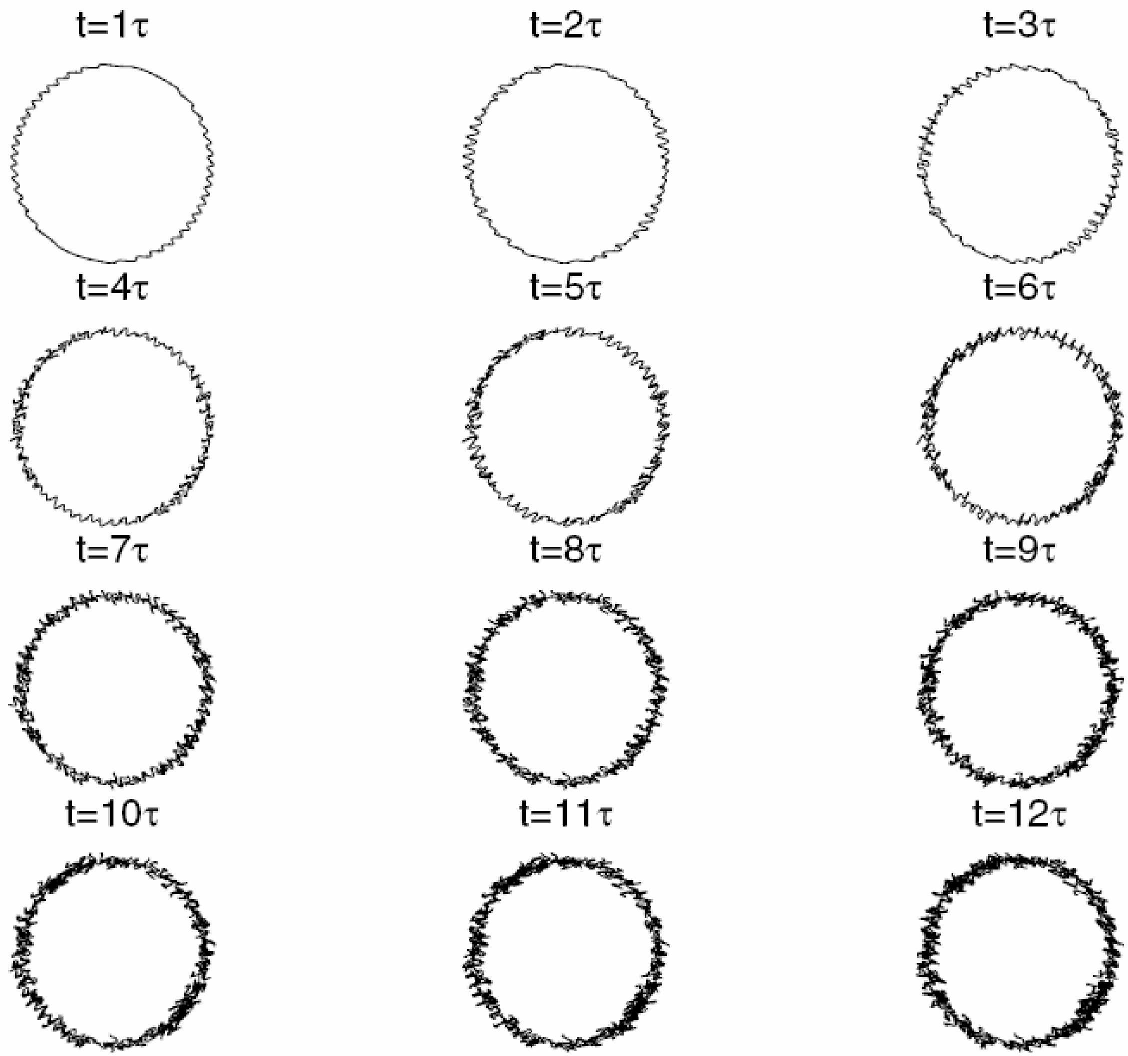


Figure 3: Stretching of a big blob $r \gg 1$, where r is the initial radius of the blob. The dotted circle representing the initial patch may not be visible beneath the wiggly boundary of the blob.

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*:

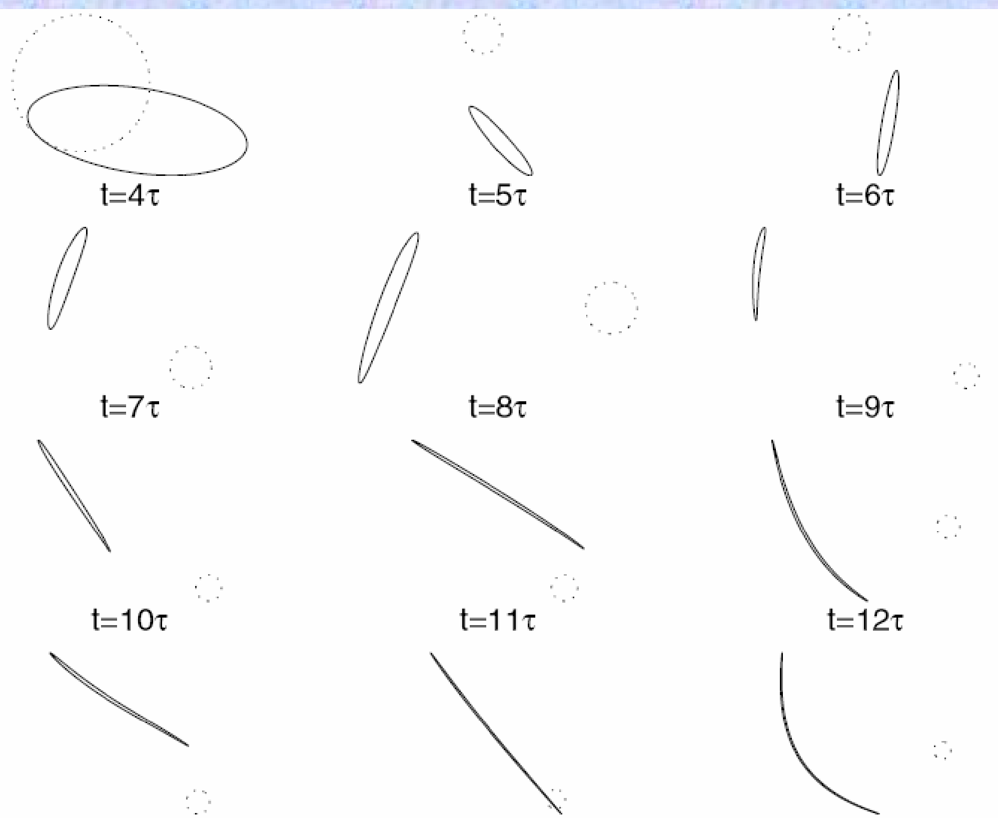


Figure 1: Stretching of a small spot, $r \ll 1$ where r is the initial radius of the spot, by a succession of random sinusoidal flows. The dotted circle is the initial spot.

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:

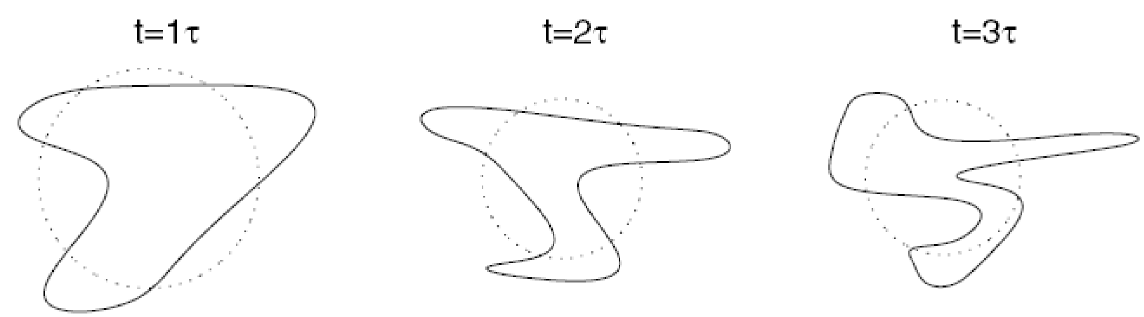
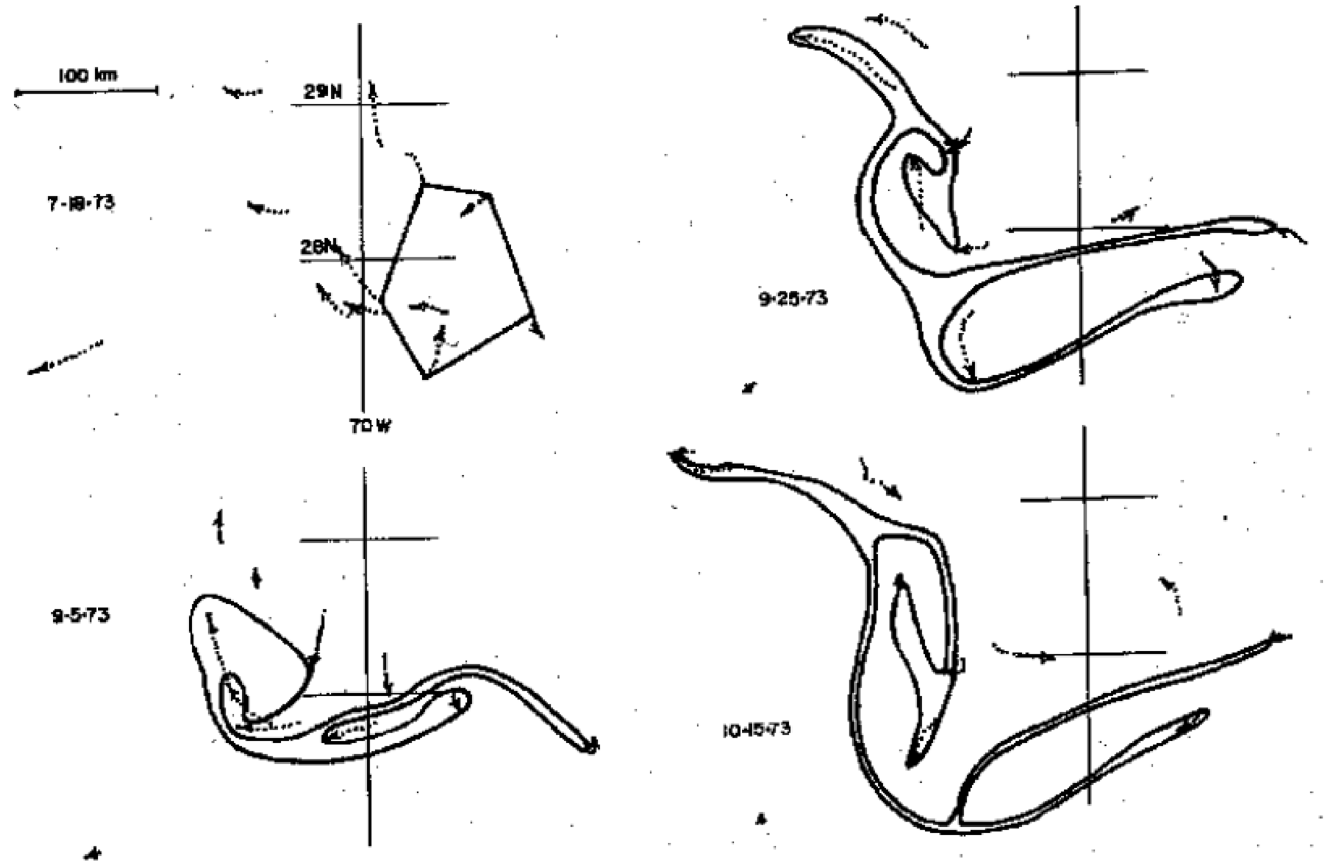


Figure 2: Stretching of a blob with $r = 1$, where r is the initial radius. The dotted circle is the initial patch.

Observation:

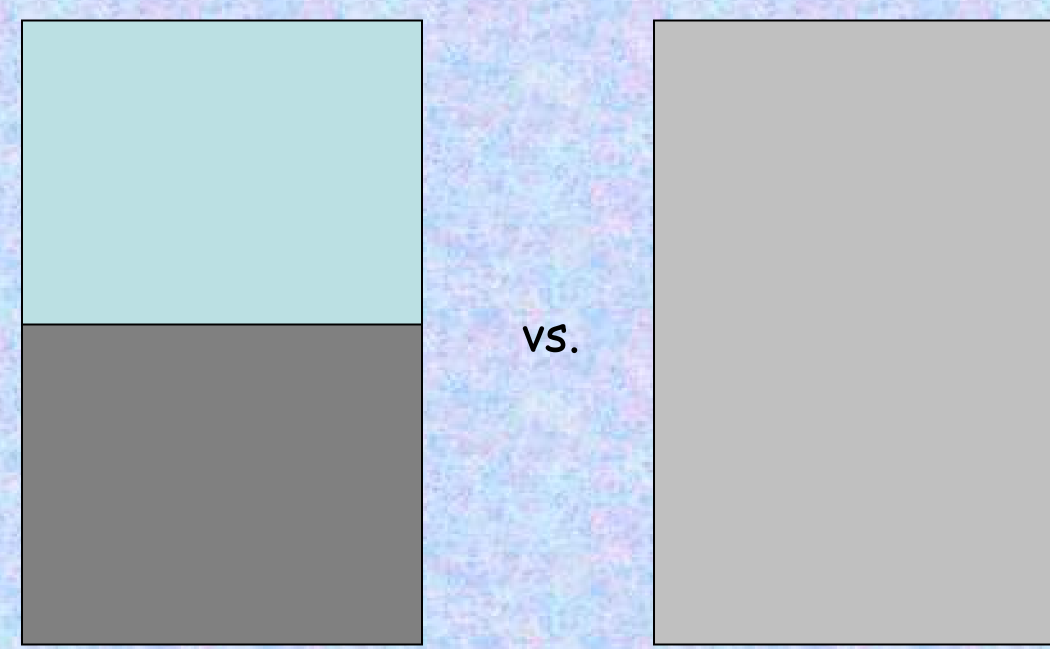


Distortion over a 3-month period of a polygon connecting 5 SOFAR floats.

Floats in an eddy field (Freeland, Rhines, and Rossby, 1977)

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:

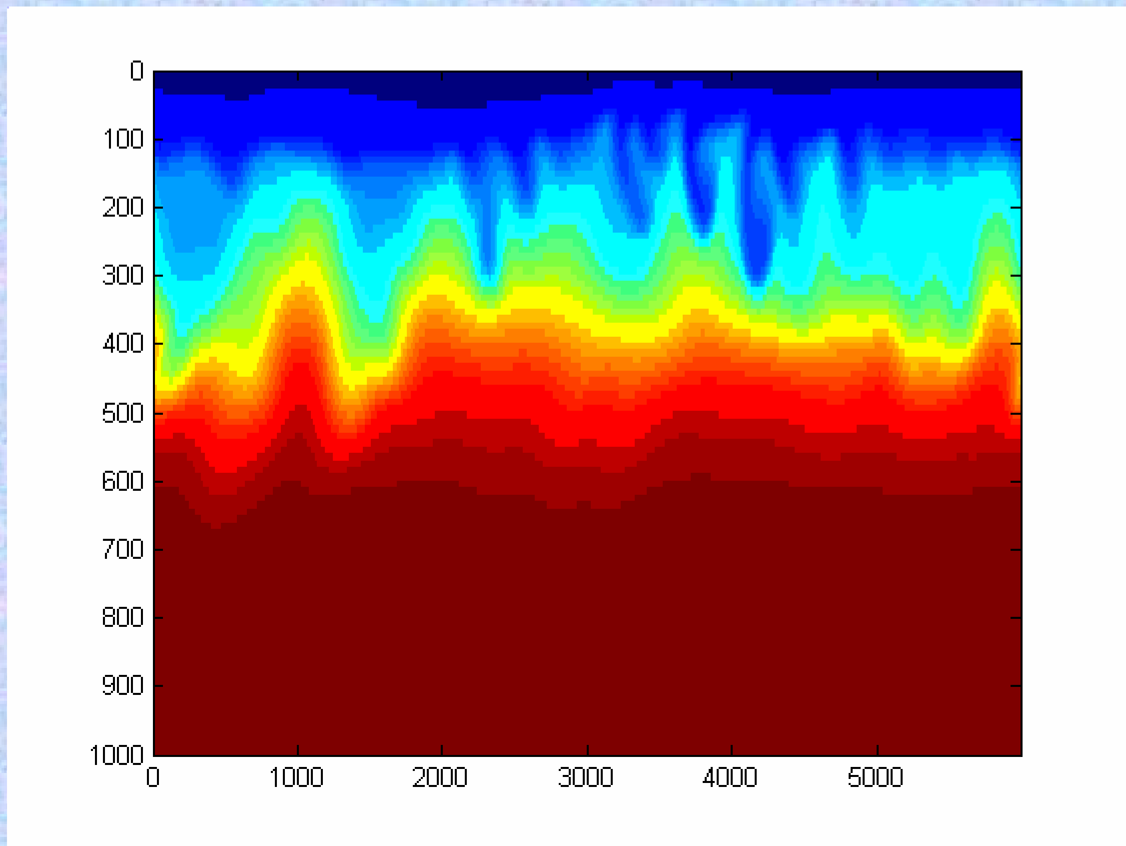
$$Ri = \frac{\dfrac{-g}{\rho}\dfrac{\partial \rho}{\partial z}}{\left(\dfrac{\partial u}{\partial z}\right)^2}$$

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).

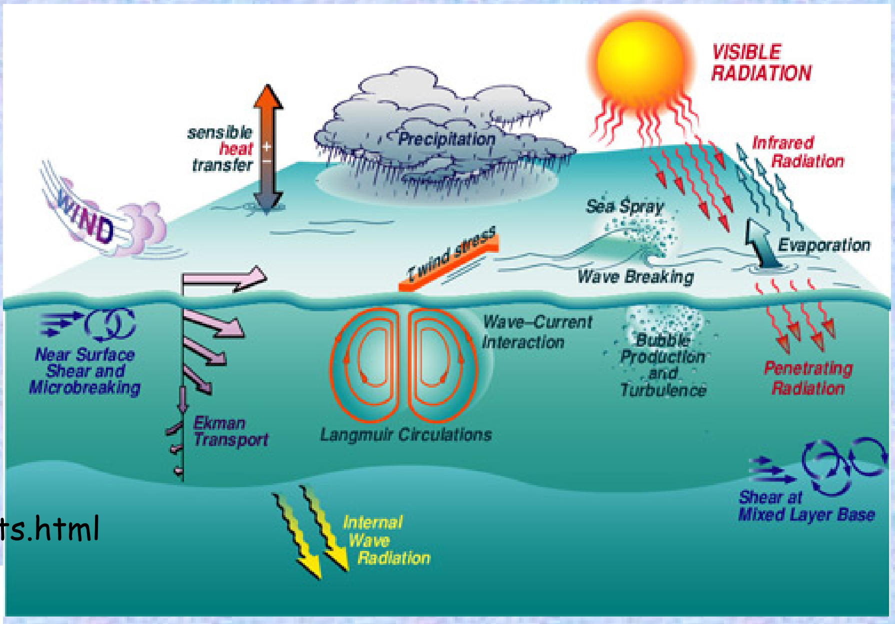


http://www.ifm.uni-hamburg.de/~wwwsh/aim.html

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

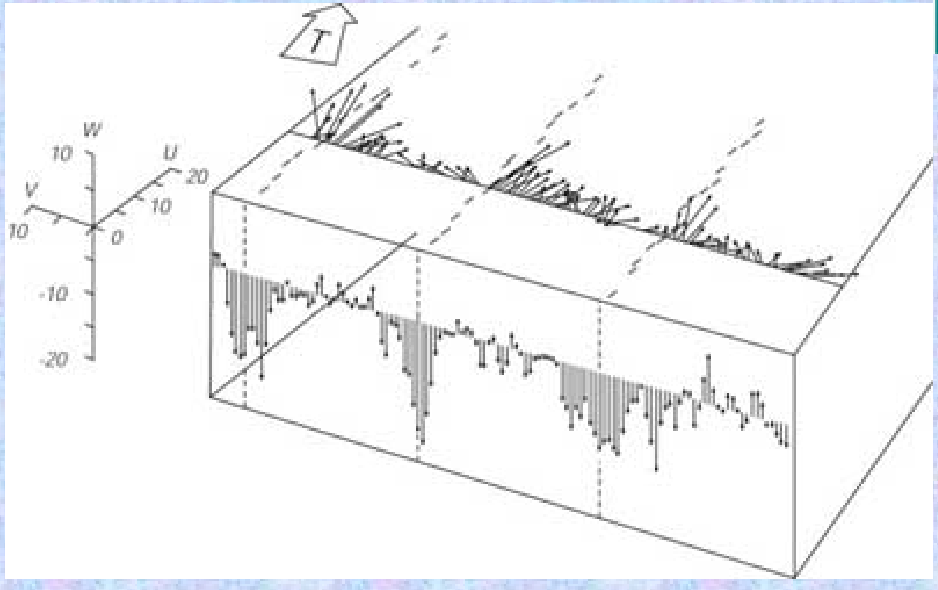
What causes mixing in the oceans?

II. Wind –Entrainment of fluid by Langmuir circulation.



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

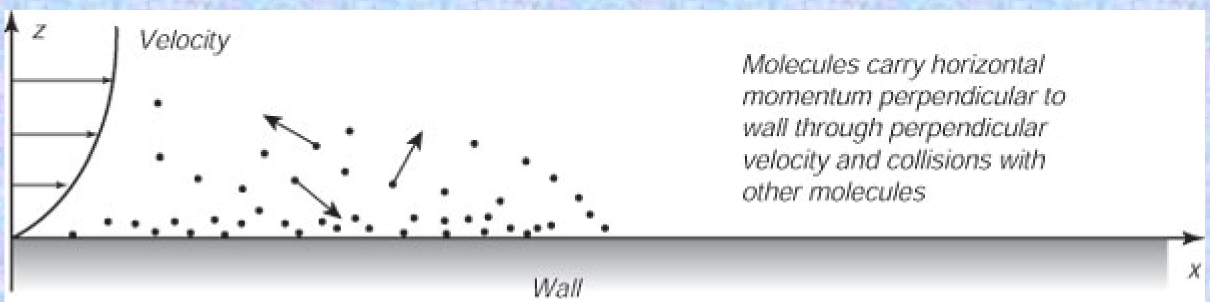
http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html



What causes mixing in the oceans?

III. Bottom stress:

bottom boudary layer (BBL)



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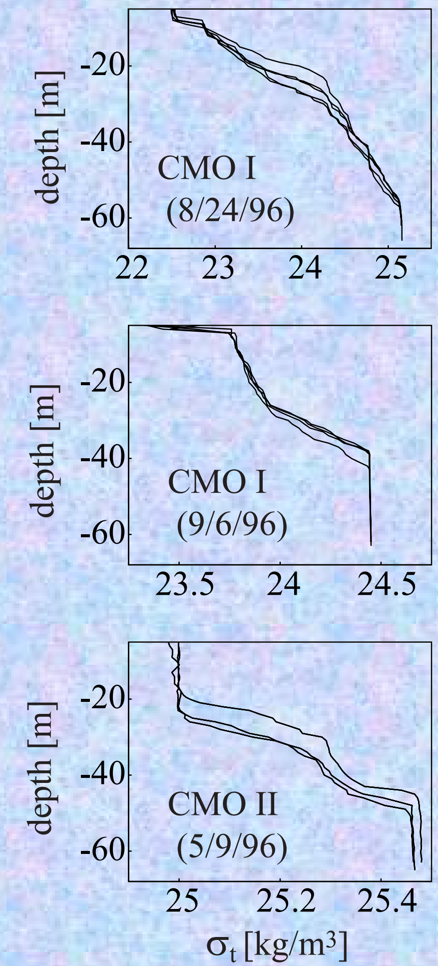


Mixing near bottom on continental shelf.

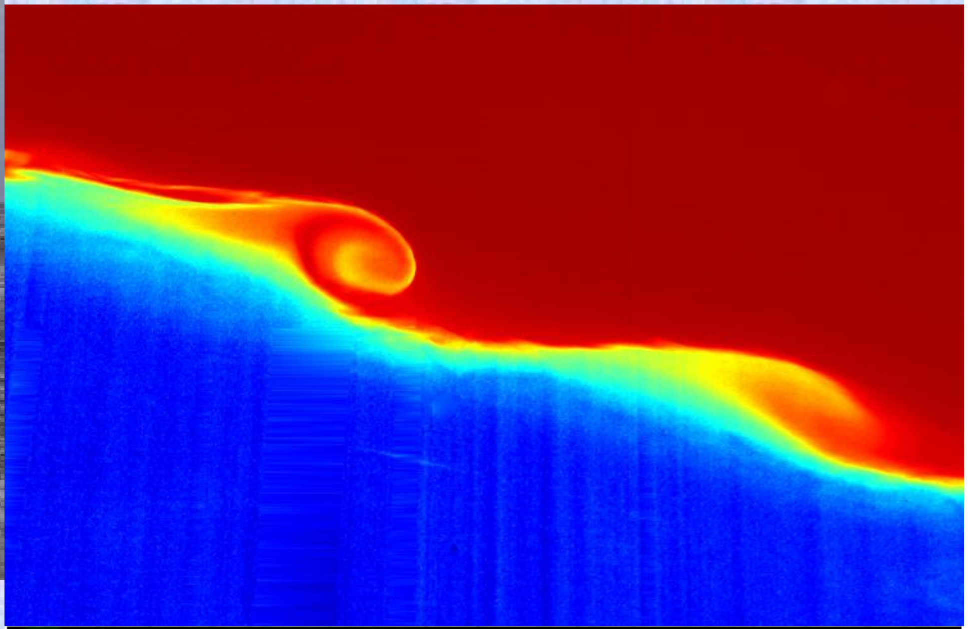
How would bottom roughness affect mixing?

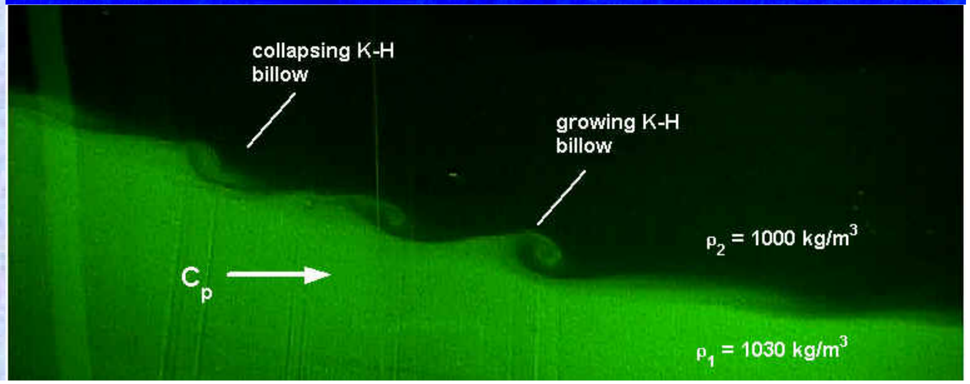
What causes mixing in the oceans?

IV. Breaking surface and internal waves.

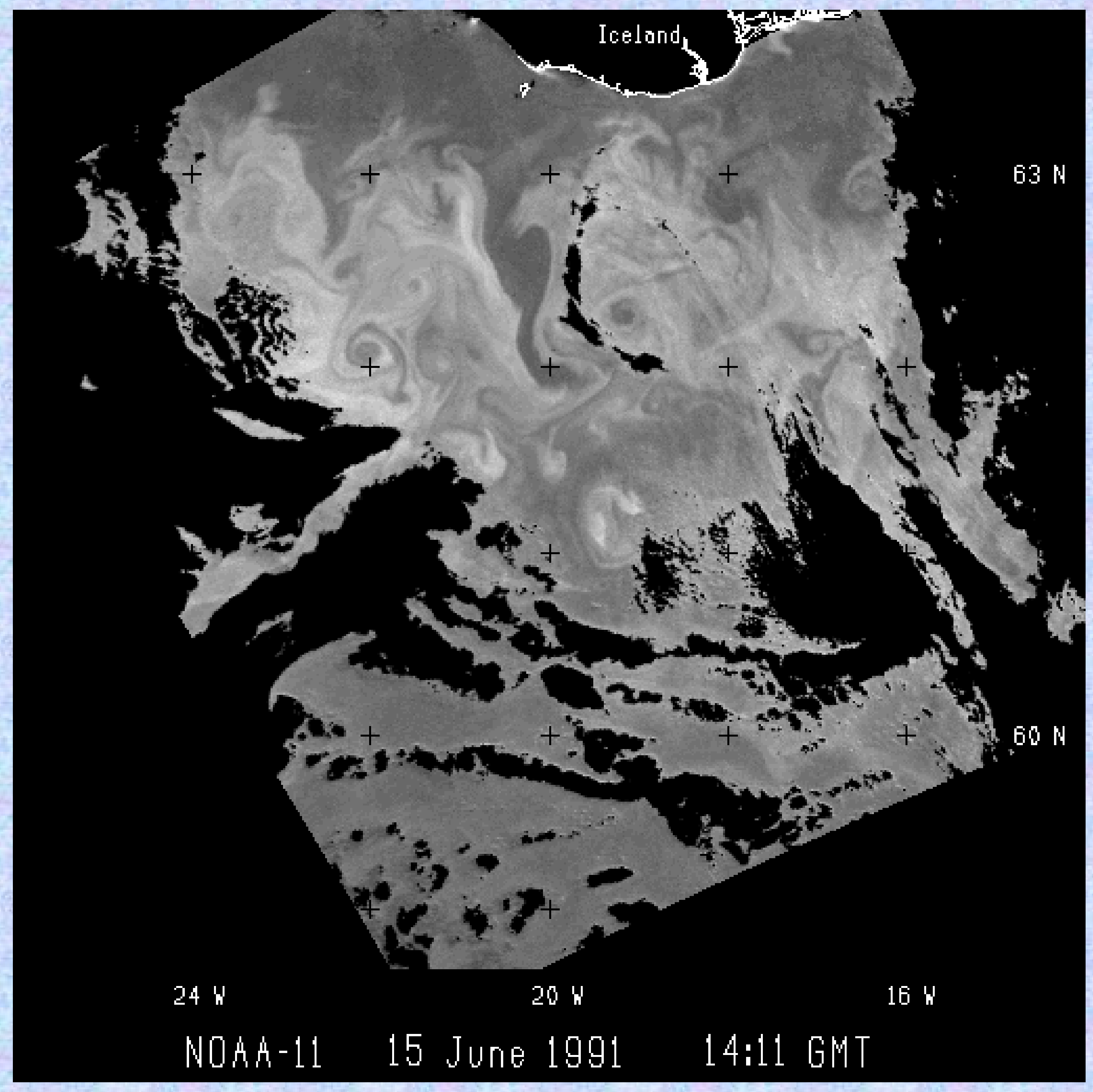
http://psc.apl.washington.edu/HLD/CBL/Teacher/Webcode/020905.jad8_007.jpg

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



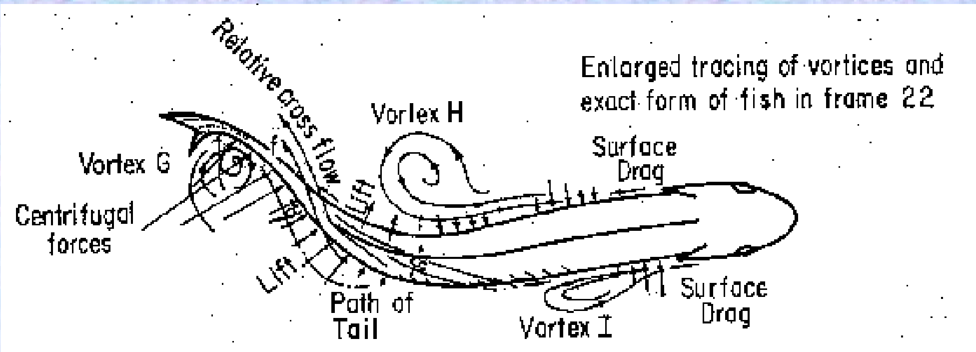


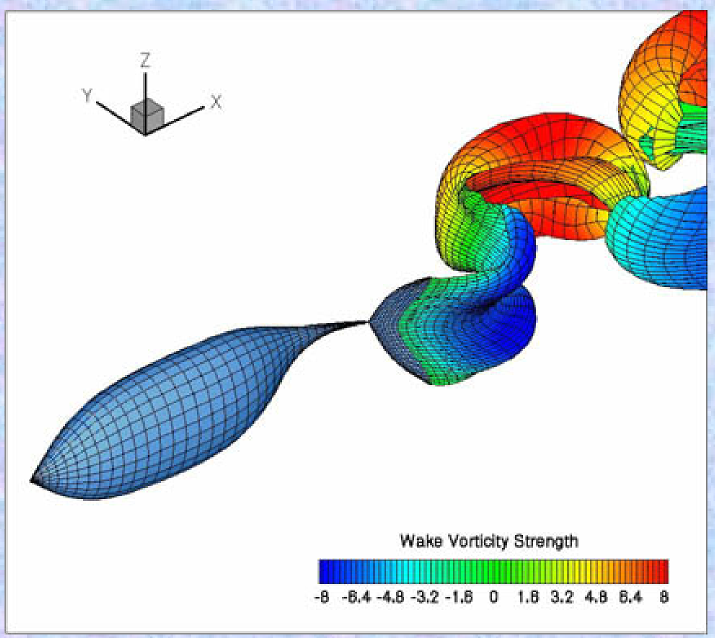
V. Stirring by eddies:

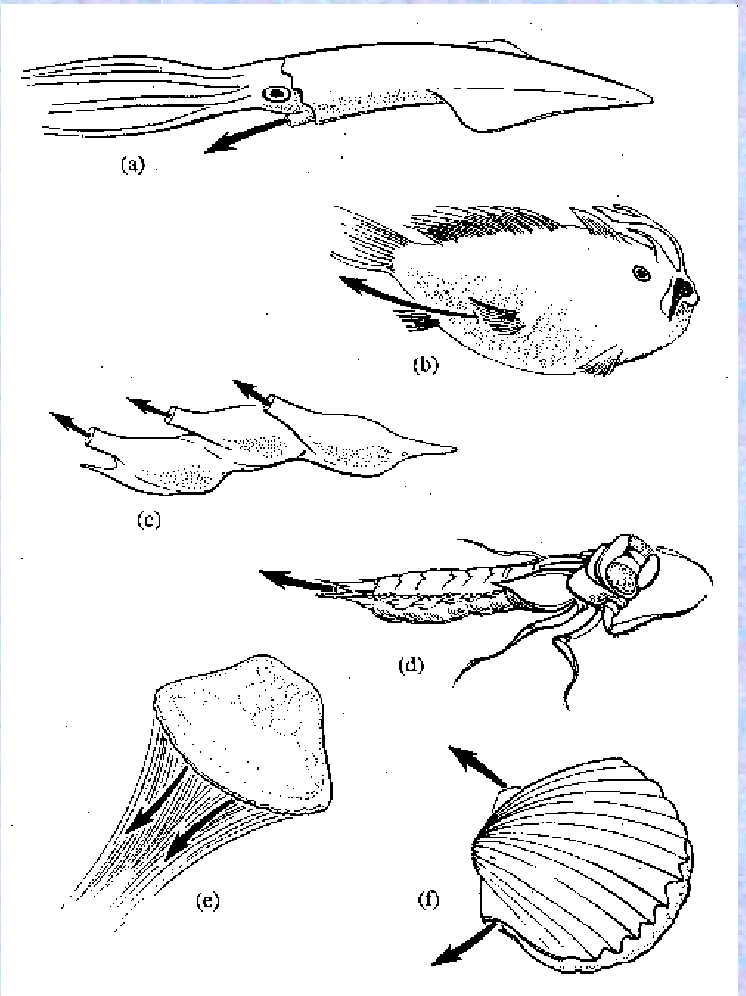


What causes mixing in the oceans?

VI. Biology.







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

Mixing and the oceanic thermocline:

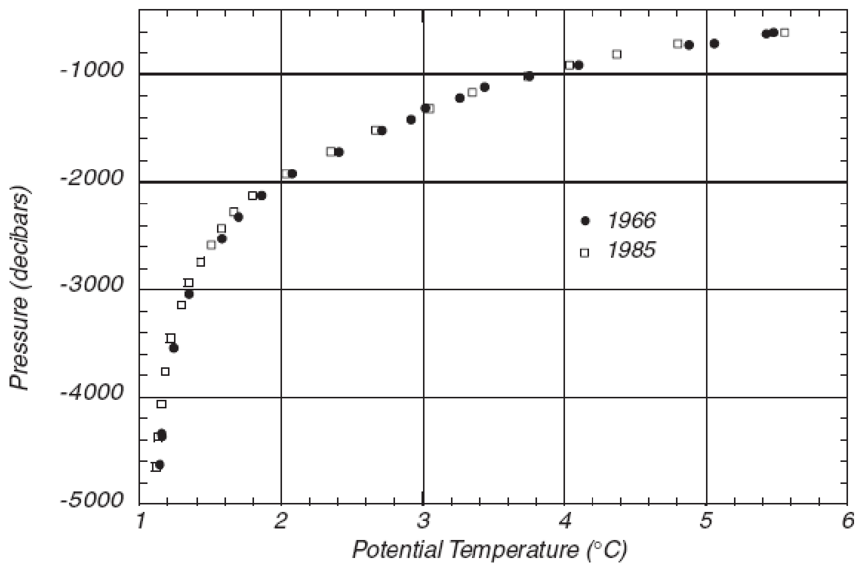
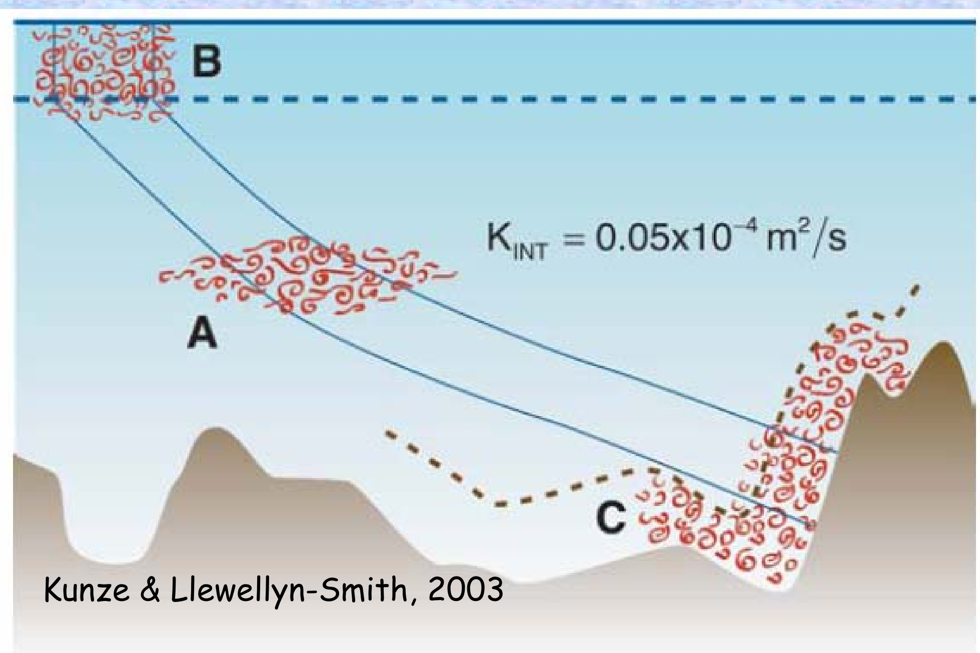


Figure 8.8 Potential temperature measured as a function of depth (pressure) near 24.7°N, 161.4°W in the central North Pacific by the *Yaquina* in 1966 (•), and by the *Thompson* in 1985 (□). Data from *Atlas of Ocean Sections* produced by Swift, Rhines, and Schlitzer.

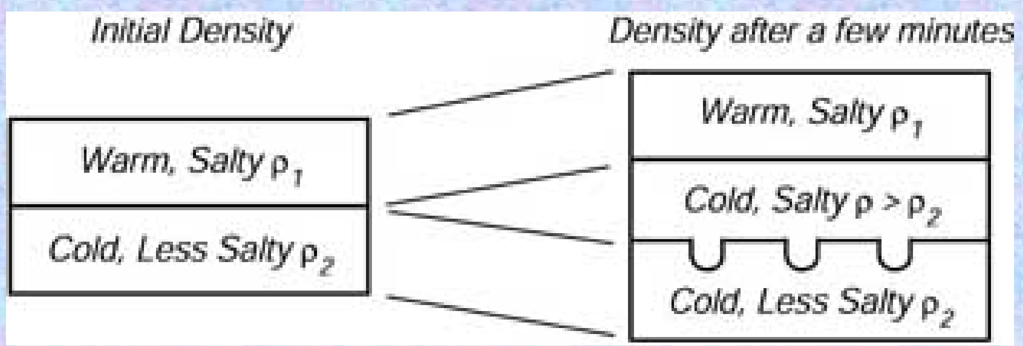
If we equate turbulent diffusion with upward advection we need an eddy diffusivity which is 20 times higher than observed in the open NA ocean.



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



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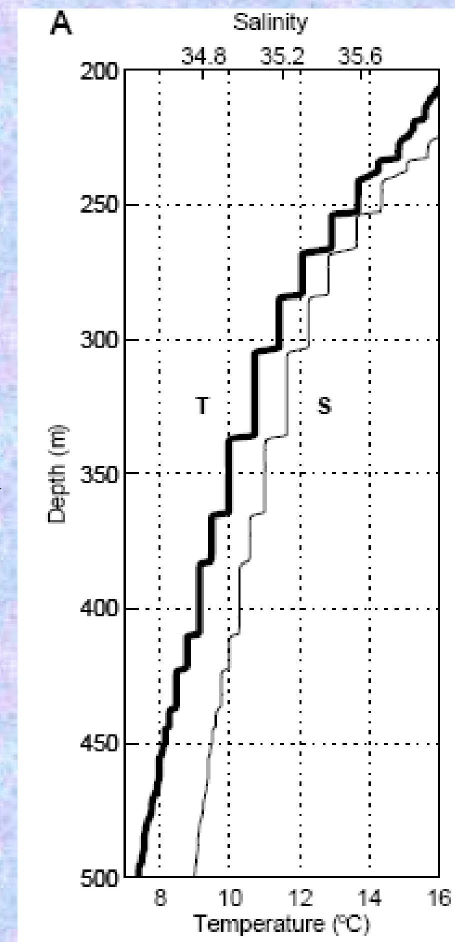
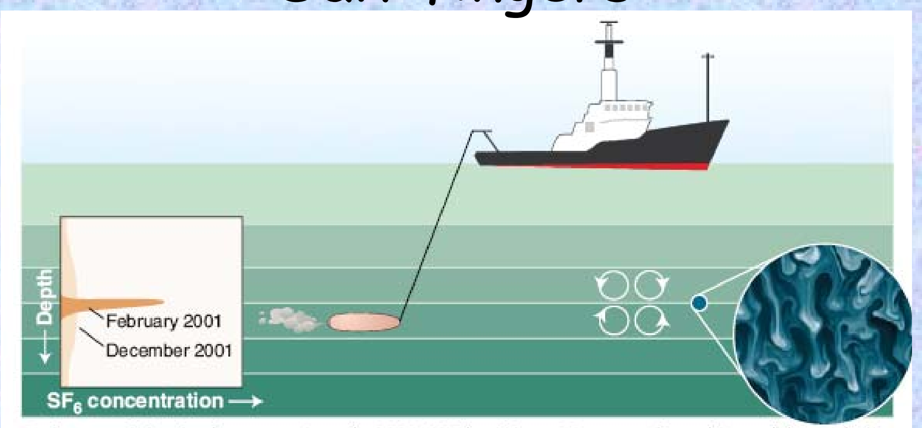


Salt fingers



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

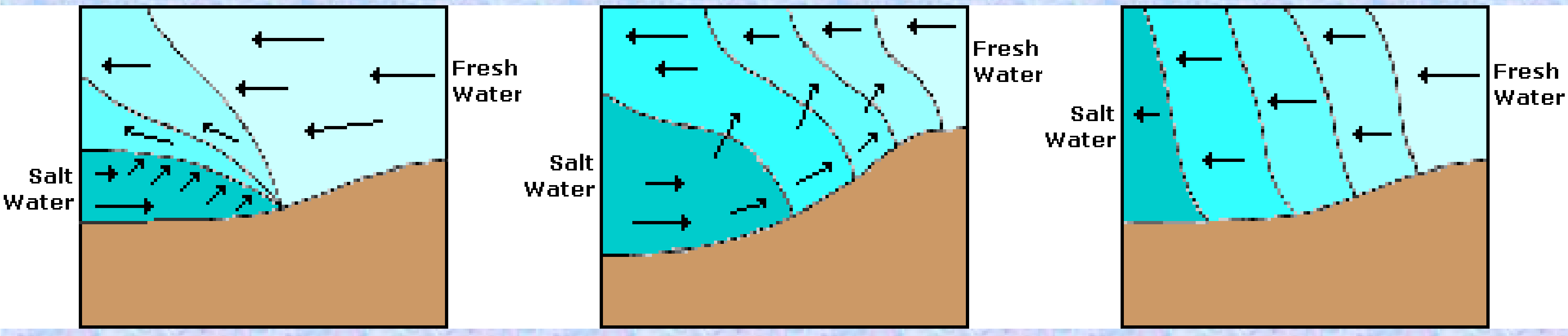
R. W. Schmitt,* J. R. Ledwell, E. T. Montgomery, K. L. Polzin, J. M. Toole

SCIENCE VOL 308 29 APRIL 2005

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

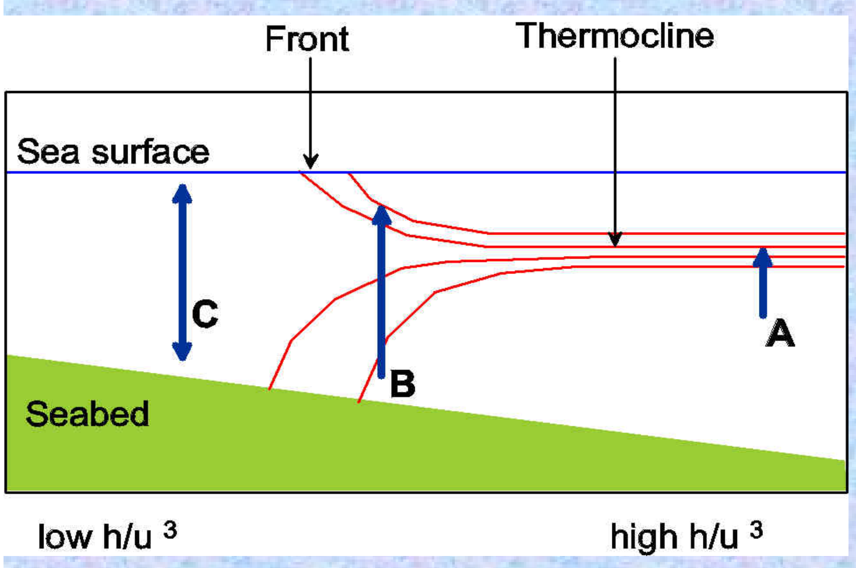
VIII. Mixing by tides:

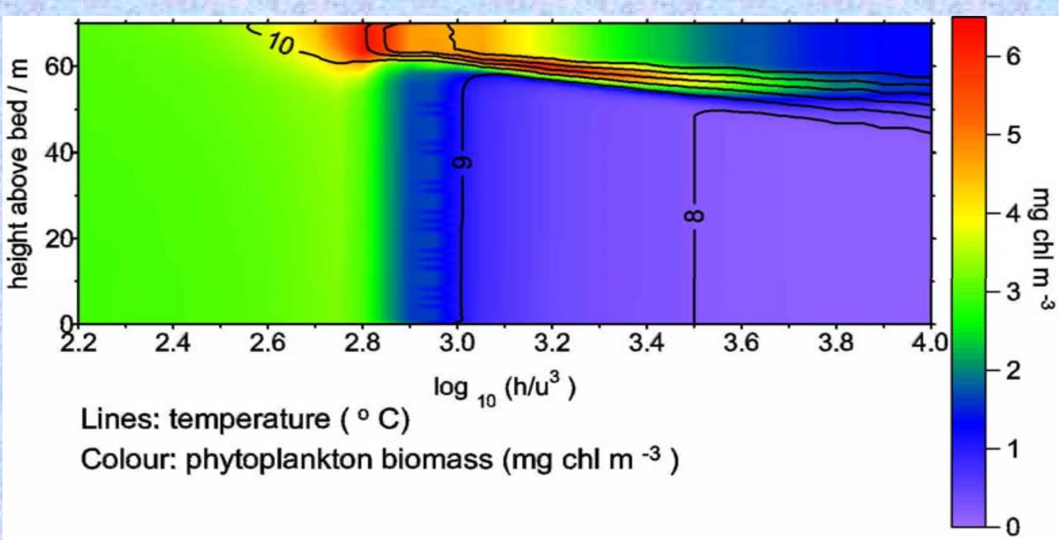
Can dominate distributions of properties in estuaries:



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

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?