SMS 303: Integrative Marine Sciences III

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- 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:

\[ \frac{\partial [C]}{\partial t} = -\frac{\partial F}{\partial x} = D \frac{\partial^2 [C]}{\partial x^2} \]

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

\[\rightarrow\] Diffusion coefficient of a typical organic molecule \(\sim 0.05 \text{ cm}^2/\text{sec} \text{ 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 \(\leftrightarrow\) Movie.

• Stretch and fold (dough, candy) \(\leftrightarrow\) 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.

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 take 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 $\sim (d\rho/dz)^{-1}$

The Richardson number: 

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

Stratification, inhibit mixing (when $>0$)

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

http://www.hpl.umces.edu/~lzhong/mixed_layer/sml.htm
What causes mixing in the oceans?

III. Bottom stress:

*Molecules carry horizontal momentum perpendicular to wall through perpendicular velocity and collisions with other molecules*

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

http://psc.apl.washington.edu/HLD/CBL/Teacher/Webcode/020905_jad8_007.jpg
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.

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
Small organisms do a lot of work swimming in water (quantified by $\varepsilon$, 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 $B$.

Visser, Science, 2007
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- $D_{\text{temperature}} = 100 \times D_{\text{salt}}$.

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

Salt fingers

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


Vertical eddy diffusion~ $0.9 \times 10^{-4}$ m$^2$/s
VIII. Mixing by tides (combination of bottom stress and lateral gradients):

Can dominate distributions of properties in estuaries and shallow seas:

Can dominate the distribution of properties in shallow shelves:

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

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

http://www.soes.soton.ac.uk/staff/js/phyto_1d.html
T-S diagrams and mixing

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.

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