SMS 303: Integrative Marine Sciences III

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• 4 weeks & topics: waves, tides, mixing and Coriolis.
  Change in plan – Coriolis 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.

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

In 1-dimension: \( F = -D \frac{d[C]}{dx} \)

What are the units of the diffusion coefficient?

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

\[
\frac{\partial [C]}{\partial t} = \frac{\partial F}{\partial x} = -D \frac{\partial^2 [C]}{\partial x^2}
\]
How long will it take for a perfume to diffuse in the class by pure diffusion?

→ Diffusion coefficient of a typical organic molecule \( \sim 0.05 \text{ cm}^2/\text{sec} \) 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.

\[ D = \text{constant} \times \frac{\text{Temperature}}{\text{radius of molecules} \times \text{medium's viscosity}} \]

**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.
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 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 ~ \((d\rho/dz)^{-1}\)

The Richardson number:

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

Mixing occurs when \(\text{Ri} < 0.25\).
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://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:

Mixing near bottom on continental shelf.

How would bottom roughness affect mixing?

http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html
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:
What causes mixing in the oceans?

VI. Biology.

Importance has been dismissed. Some think it contributes significantly to ocean mixing.
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 - $D_{\text{temperature}} = 100 \times D_{\text{salt}}$.

Salt fingers

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


Vertical eddy diffusion $\sim 0.9 \times 10^{-4} \text{ m}^2/\text{s}$
VIII. Mixing by tides:

*Can dominate distributions of properties in estuaries:*

[Image showing the mixing of salt and fresh water in estuaries]

*Can dominate the distribution of properties in shallow shelves:*

[Graph showing thermal and nutrient stratification in shallow shelves]

[Links to resources for further reading]
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?