Community Ocean Vertical Mixing (CVMix) Parameterizations

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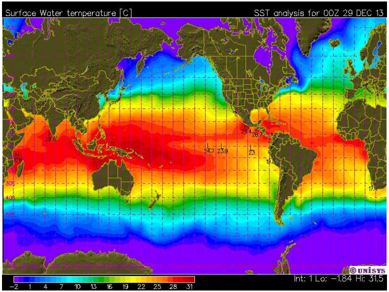
Outline

Why is Vertical Mixing Important to Ocean Models?



http://weather.unisys.com/archive/sst/sst-131229.gif (Dec 29, 2013)

Basics

- Sea surface temperature (SST) has a major role in atmosphere ↔ ocean energy exchange
- Vertical mixing is one of many processes affecting SST
  - Occurs on scales that are not resolved by current ocean models, need to use parameterization instead
- Other physical quantities (tracers, salinity, etc) also affected by mixing

Mixing in Ocean Models

Current State

- Numerous techniques for parameterizing the mixing process
- Model developers choose their favorite parameterization(s) and code them up as part of the ocean model

CVMix Project

- Our goal: produce an easy-to-use library containing a range of parameterizations
- Secondary goal: provide a stand-alone driver to test the library on its own
  - Note: we use the term "stand-alone driver" a bit loosely. CVMix can compute single-column diffusivities given proper input, but lacks the capability to see how diffusivities change over time.

Why CVMix?

Driving Force

Breckenridge 2012: MPAS-O did not have a KPP module yet and MOM5 was using an outdated implementation that GFDL wanted to improve on for their next generation model.

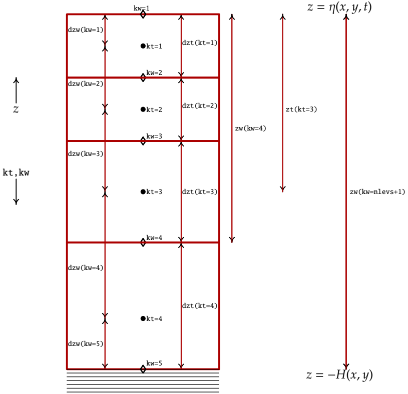
- CVMix is now used in development of MPAS-O and MOM6, and will [eventually] replace the mixing modules in POP.

Other Benefits

1. Reduce duplicate code – for example, static mixing occurs as a step in many parameterizations
2. CSEG is working to include non-POP / non-data ocean models in CESM
    - Vertical mixing library allows [some] physics to stay the same even if dynamics change
    - Allow more detailed model inter-comparisons

Vertical Mixing Overview

- Divide column into `nlevs` levels
- Data on cell centers and interfaces
- Center index $kt = 1 \ldots$ `nlevs`
- Interface index $kw = 1 \ldots$ `nlevs+1`
- Depth z
  - η at surface
  - 0 at average sea level
  - $-H(x, y)$ at bottom (positive up!)



What Does a Vertical Mixing Parameterization Look Like?

- Inputs: combination of parameters and physical values in column
- Outputs: viscosity (ν) and tracer diffusivity (κ) coefficients on cell interfaces

[Some] Mixing Parameterizations

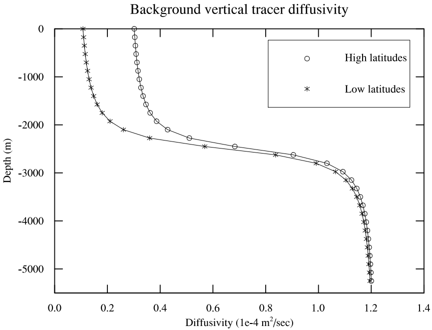
1. **Static background mixing**
   - Constant mixing
   - Bryan-Lewis (1979)
   - Henyey et al. (1986)
2. **Shear-induced mixing** ("Richardson number mixing")
   - Pacanowski and Philander (1981)
   - Large et al. (1994), henceforth LMD94
   - Jackson et al. (2008)
3. **Tidal mixing**
   - Simmons et al. 2004
   - Polzin (2009) / Melet et al. (2013)
4. **Double diffusion mixing** (Schmitt, 1994 / LMD94 / Danabasoglu et al., 2006)
5. **K-profile parameterization** ("KPP"; LMD94)
6. **Vertical convective mixing** (density based as well as Brunt-Väisälä)

Blue indicates method is already in package.

Bryan-Lewis Profile

Want diffusivity to increase towards bottom of ocean.

At right: diffusivity profile of two columns representing columns in different latitudes.



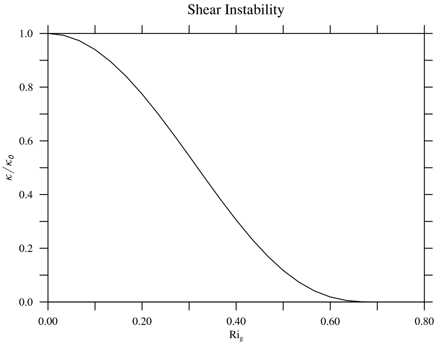
Diffusivity and Viscosity Depend on Depth

$$\begin{aligned}\kappa &= c_0 + \frac{c_1}{\pi}\tan^{-1}\Big(c_2((-z) - c_3)\Big) \\ \nu &= \text{Pr}\kappa\end{aligned}$$

Shear Mixing

Want diffusivity to decrease as Richardson number (Ri) increases; $\kappa = 0$ if $\text{Ri} \geq \text{Ri}_0 = 0.7$.

At right: The stand-alone driver produces the shear mixing diffusivity profile plot from Fig. 3 of LMD94.



Diffusivity and Viscosity Depend on Richardson Number

$$\begin{aligned} \kappa &= \begin{cases} \kappa_0 & \text{Ri} \leq 0 \\ \kappa_0[1-(\text{Ri}/\text{Ri}_0)^{p_1}]^{p_2} & 0 < \text{Ri} < \text{Ri}_0 \\ 0 & \text{Ri} \geq \text{Ri}_0 \end{cases} \\ \nu &= \text{Pr}\kappa \end{aligned}$$

Double Diffusion Mixing

Two regimes

Determine which regime we are in via stratification parameter

$$\mathrm{R}_\rho = \frac{\alpha}{\beta}\left(\frac{\partial\Theta/\partial z}{\partial S/\partial z}\right),$$

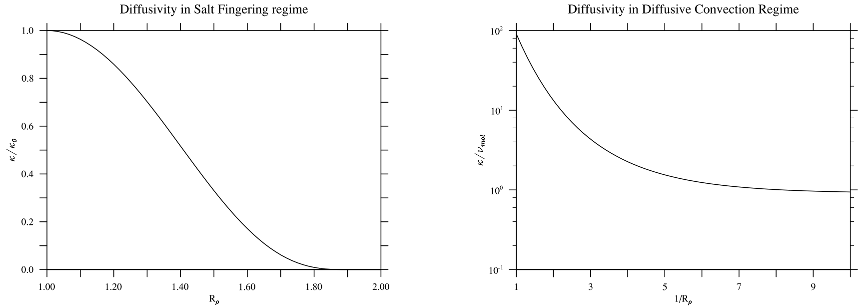
where α is the thermal expansion coefficient and β is the haline contraction coefficient:

1. Salt Fingering ($\partial S/\partial z > 0$ and $1 < \mathrm{R}_\rho < \mathrm{R}_\rho^0$); salt water above fresher water $\Rightarrow$ salt water will sink
2. Diffusive Convective Instability ($\partial\Theta/\partial z < 0$ and $0 < \mathrm{R}_\rho < 1$); cold water above warm water $\Rightarrow$ cold water will sink

And that's not all...

Double diffusion also introduces idea of different diffusivity for temperature and salinity (κ_Θ and κ_S, respectively).

Double Diffusion Mixing



Diffusivity profiles for the two regimes (Fig. 4 in LMD94).

Salt-Fingering Regime

$$\kappa_S = \kappa_0 \left[1 - \left(\frac{\mathrm{R}_\rho - 1}{\mathrm{R}_\rho^0 - 1}\right)^{p_1}\right]^{p_2}$$

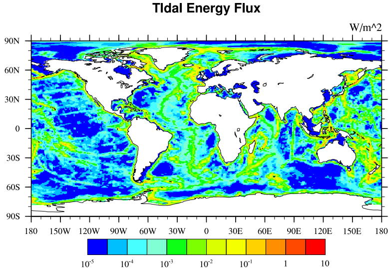
$$\kappa_\Theta = 0.7\kappa_S$$

Diffusive Convective Regime

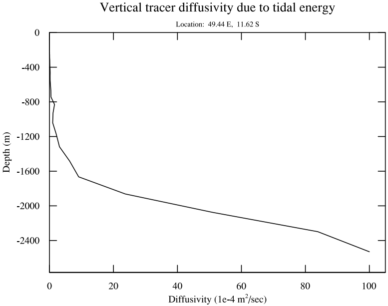
$$\kappa_\Theta = \nu_{\mathrm{mol}} \cdot c_1 \exp\left(c_2 \exp\left[c_3 \frac{1 - \mathrm{R}_\rho}{\mathrm{R}_\rho}\right]\right)$$

$$\kappa_S = \max(0.15\mathrm{R}_\rho, 1.85\mathrm{R}_\rho - 0.85)\kappa_\Theta$$

Tidal Mixing



Tidal Energy Flux Map



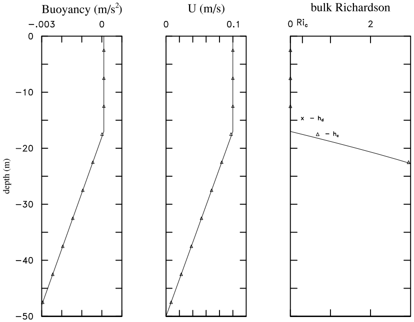
Diffusivity North of Madagascar

Diffusivity Depends on Tidal Energy Flux, Depth, Density, and Buoyancy

$$\kappa = \frac{q\Gamma E(x,y)F(x,y,z)}{\rho N^2}$$

$$F(x,y,z) = \frac{e^{-z/\zeta}}{\zeta\left(e^{H(x,y)/\zeta} - e^{-\eta(x,y)/\zeta}\right)}$$

KPP Mixing



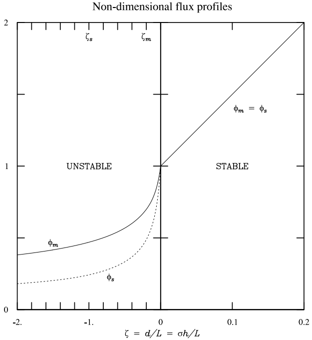
Bouyancy, velocity, and bulk Richardson values (Fig. C1 in LMD94).

The boundary layer depth (h) computed based on bulk Richardson number

$$Ri_b(z) = \frac{-z(B_r - B(z))}{|\mathbf{V}_r - \mathbf{V}(z)|^2 + \mathbf{V}_t^2(z)}$$

$\mathbf{V}_t$ is unresolved velocity shear, see Eq. (23) in LMD94.

KPP Mixing



Flux profiles ϕ (Fig. B1 in LMD94).

Inside the boundary layer, diffusivity is given by

$$\nu|\kappa = hw_{m|s}(-z/h)G(-z/h)$$

$w_{m|s}$, the turbulent velocity scale for *m*omentum or *s*calar quantities, is inversely proportional to $\phi_{m|s}$; G is a shape function defined to ensure a smooth κ.

What's Been Done and What's Coming

Progress over last 18 months

- Infrastructure for the stand-alone drivers (building, IO, etc) is done
- Modules for the mixing methods mentioned in blue on a previous slide have been coded up
- Testing has begun in MOM, POP, & MPAS-O

Still to do before public release

1. More testing for KPP (issues with vertical resolution?)
2. Document APIs
3. Document process for adding modules to library
    - Likely will involve making code available on github, using push / pull requests
4. Formalize unit tests, regression tests, and examples to allow easy porting

Summary

- Multi-lab collaboration to build vertical mixing library
- No change in POP interface, but changes “under the hood”
- Ability to run as a stand-alone / single-column executable
- Will be made available to public with a well-documented process allowing others to add modules to the library

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