Ocean Modeling - EAS 8803

Vertical Mixing Scheme

K-Profile Parameterization

The vertical mixing parameterization introduced by Large, McWilliams and Doney (1994) is a versatile first order scheme which has been shown to perform well in open ocean settings

Mellor-Yamada 2.5

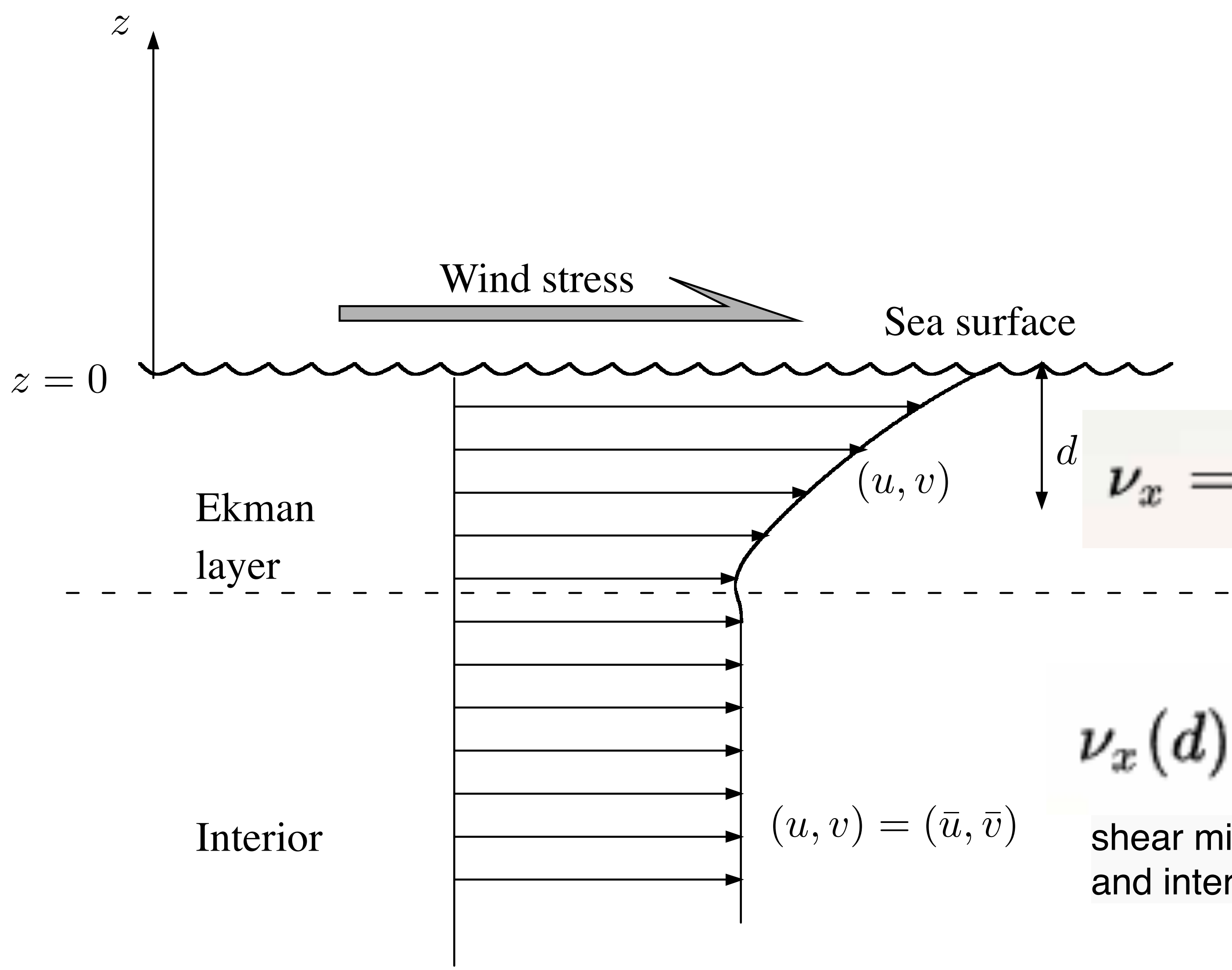
One of the more popular closure schemes is that of Mellor and Yamada (1982)

Generic Length Scale

Umlauf and Burchard (2003) have come up with a generic two-equation turbulence closure scheme which can be tuned to behave like several of the traditional schemes, including that of Mellor and Yamada 2.5 (above)

https://www.myroms.org/wiki/Vertical_Mixing_Parameterizations

How to we mix momentum and tracer fluxes in the upper ocean?



Surface Layer

$$\nu_x = h_{sbl} w_x(\sigma) G_x(\sigma)$$

Interior

$$\nu_x(d) = \nu_x^s + \nu_x^d + \nu_x^w$$

shear mixing, double-diffusive mixing and internal wave generated mixing

Figure 8-6 The surface Ekman layer generated by a wind stress on the ocean.

Surface Layer

$$\nu_x = h_{sbl} w_x(\sigma) G_x(\sigma)$$

Surface Boundary layer depth

The boundary layer depth h_{sbl} is calculated as the minimum of the Ekman depth, estimated as,

$$h_e = 0.7 u_* / f$$

(where u_* is the friction velocity $u_* = \sqrt{\tau_x^2 + \tau_y^2 / \rho}$)

Turbulent velocity scale

To estimate w_x (where x is m - momentum *or* s - any scalar) throughout the boundary layer, surface layer similarity theory is utilized. Following an argument by Troen and Mahrt (1986), Large et al. estimate the velocity scale as

$$we_x = \frac{\kappa u_*}{\phi_x(\zeta)}$$ (

where ζ is the surface layer stability parameter defined as z/L. ϕ_x is a non-dimensional flux profile

Surface Layer

$$\nu_x = h_{sbl} w_x(\sigma) G_x(\sigma)$$

The shape function

The non-dimensional shape function $G(\sigma)$ is a third order polynomial with coefficients chosen to match the interior viscosity at the bottom of the boundary layer and Monin-Obukhov similarity theory approaching the surface. This function is defined as a 3rd order polynomial.

$$G(\sigma) = a_o + a_1\sigma + a_2\sigma^2 + a_3\sigma^3 \tag{10}$$

with the coefficients specified to match surface boundary conditions and to smoothly blend with the interior,

$$\begin{aligned} a_o &= 0 \\ a_1 &= 1 \\ a_2 &= -2 + 3\frac{\nu_x(h_{sbl})}{hw_x(1)} + \frac{\partial_x \nu_x(h)}{w_x(1)} + \frac{\nu_x(h)\partial_\sigma w_x(1)}{hw_x^2(1)} \\ a_3 &= 1 - 2\frac{\nu_x(h_{sbl})}{hw_x(1)} - \frac{\partial_x \nu_x(h)}{w_x(1)} - \frac{\nu_x(h)\partial_\sigma w_x(1)}{hw_x^2(1)} \end{aligned} \tag{11}$$

where $\nu_x(h)$ is the viscosity calculated by the interior parameterization at the boundary layer depth.

Interior Mixing

Interior Mixing

$$\nu_x(d) = \nu_x^s + \nu_x^d + \nu_x^w$$

Shear generated mixing

The shear mixing term is calculated using a gradient Richardson number formulation, with viscosity estimated as:

$$\nu_x^s = \begin{cases} \nu_0 & Ri_g < 0\,, \\ \nu_0[1-(Ri_g/Ri_0)^2]^3 & 0 < Ri_g < Ri_0\,, \\ 0 & Ri_g > Ri_0\,. \end{cases} \tag{16}$$

where ν_0 is 5.0×10^{-3}, $Ri_0 = 0.7$.

Double diffusive processes

The second component of the interior mixing parameterization represents double diffusive mixing. From limited sources of laboratory and field data LMD parameterize the salt fingering case ($R_\rho > 1.0$)

$$\nu_s^d(R_\rho) = \begin{cases} 1 \times 10^{-4}[1-(\frac{(R_\rho-1)}{R_\rho^0-1})^2)^3 & \text{for } 1.0 < R_\rho < R_\rho^0 = 1.9, \\ 0 & \text{otherwise.} \end{cases} \tag{17}$$

$$\nu_\theta^d(R_\rho) = 0.7\nu_s^d$$

For diffusive convection ($0 < R_\rho < 1.0$) LMD suggest several formulations from the literature and choose the one with the most significant impact on mixing (Fedorov 1988).

$$\nu_\theta^d = (1.5 \times 10^{-6})(0.909\exp(4.6\exp[-0.54(R_\rho^{-1}-1)]) \tag{18}$$

for temperature. For other scalars,

$$\nu_s^d = \begin{cases} \nu_\theta^d(1.85 - 0.85R_\rho^{-1})R_\rho & \text{for} 0.5 <= R_\rho < 1.0, \\ \nu_\theta^d 0.15R_\rho & \text{otherwise.} \end{cases} \tag{19}$$

!--\eqno{(19)}-->

Internal wave generated mixing

Internal wave generated mixing serves as the background mixing in the LMD scheme. It is specified as a constant for both scalars and momentum. Eddy diffusivity is estimated based on the data of Ledwell et al. (1993), while Peters et al. (1988) suggest eddy viscosity should be 7 to 10 times larger than diffusivity for gradient Richardson numbers below approximately 0.7. Therefore LMD use

$$\begin{aligned} \nu_m^w &= 1.0 \times 10^{-4} m^2 s^{-1} \\ \nu_s^w &= 1.0 \times 10^{-5} m^2 s^{-1} \end{aligned} \tag{20}$$

Mellor-Yamada 2.5 Closure Scheme

$$K_m = qlS_m + K_{m_{\text{background}}}$$
$$K_s = qlS_h + K_{s_{\text{background}}}$$

turbulent kinetic energy ($\frac{1}{2}q^2$) and one for the turbulent kinetic energy times a length scale ($q^2 l$).

and the stability coefficients S_m, S_h and S_q are found by solving

$$S_s\left[1-(3A_2B_2+18A_1A_2)G_h\right] = A_2\left[1-6A_1B_1^{-1}\right] \quad (28)$$

$$S_m\left[1-9A_1A_2G_h\right] - S_s\left[G_h(18A_1^2+9A_1A_2)G_h\right] = A_1\left[1-3C_1-6A_1B_1^{-1}\right] \quad (29)$$

$$G_h = \min(-\frac{l^2N^2}{q^2}, 0.028)\,. \quad (30)$$

$$S_q = 0.41S_m \quad (31)$$

The constants are set to $(A_1, A_2, B_1, B_2, C_1, E_1, E_2) = (0.92, 0.74, 16.6, 10.1, 0.08, 1.8, 1.33)$. The quantities q^2 and $q^2 l$ are both constrained to be no smaller than 10^{-8} while l is set to be no larger than $0.53q/N$.

Generic Length Scale

Umlauf and Burchard (2003) have come up with a generic two-equation turbulence closure scheme which can be tuned to behave like several of the traditional schemes, including that of Mellor and Yamada 2.5 (above). This is known as the Generic Length Scale, or GLS vertical mixing scheme and was introduced to ROMS in Warner et al. (2005). Its parameters are set in the ROMS input file.

The first of Warner et al.'s equations is the same as equation (21) with $k = 1/2q^2$. Their dissipation is given by

$$\epsilon = (c_\mu^0)^{3+p/n} k^{3/2+m/n} \psi^{-1/n} \qquad (32)$$

where ψ is a generic parameter that is used to establish the turbulence length scale. The equation for ψ is:

$$\frac{D\psi}{Dt} = \frac{\partial}{\partial z}\left(K_\psi \frac{\partial\psi}{\partial z}\right) + \frac{\psi}{k}(c_1 P_s + c_3 P_b - c_2 \epsilon F_{wall})$$

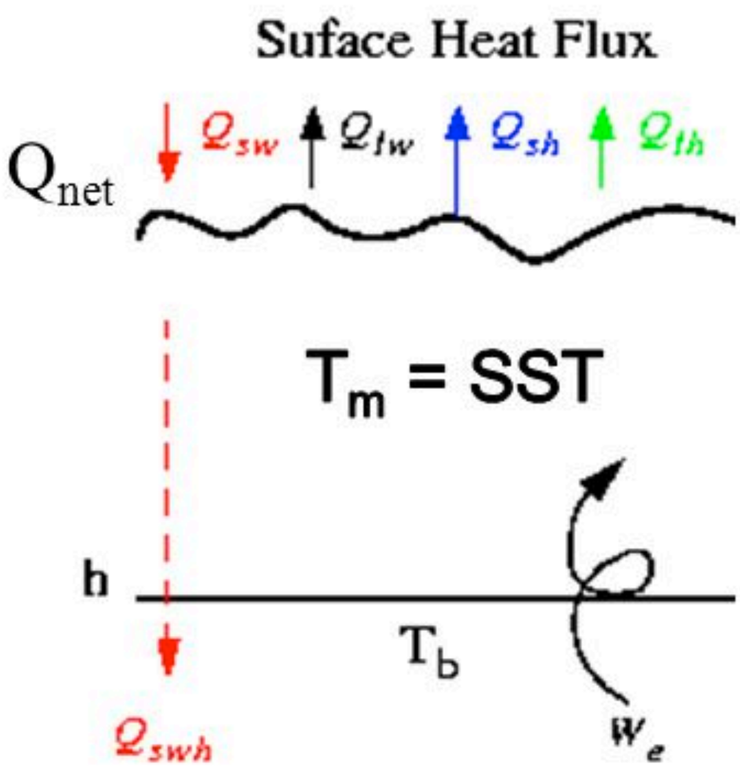
Coefficients c_1 and c_2 are chosen to be consistent with observations of decaying homogeneous, isotropic turbulence. The parameter c_3 has differing values for stable (c_3^+) and unstable (c_3^-) stratification. Also

$$\begin{aligned} \psi &= (c_\mu^0)^p k^m l^n \\ l &= (c_\mu^0)^3 k^{3/2} \epsilon{-1} \end{aligned} \qquad (34)$$

Depending on the choice of the various parameters, these two equations can be made to solve a variety of traditional two-equation turbulence closure models. The list of parameters is shown in the following table and is also given inside the comments section of the ROMS input file.

Surface Heat Fluxes

$$\frac{\partial T_m}{\partial t} = \frac{Q_{net}}{\rho c h} +$$

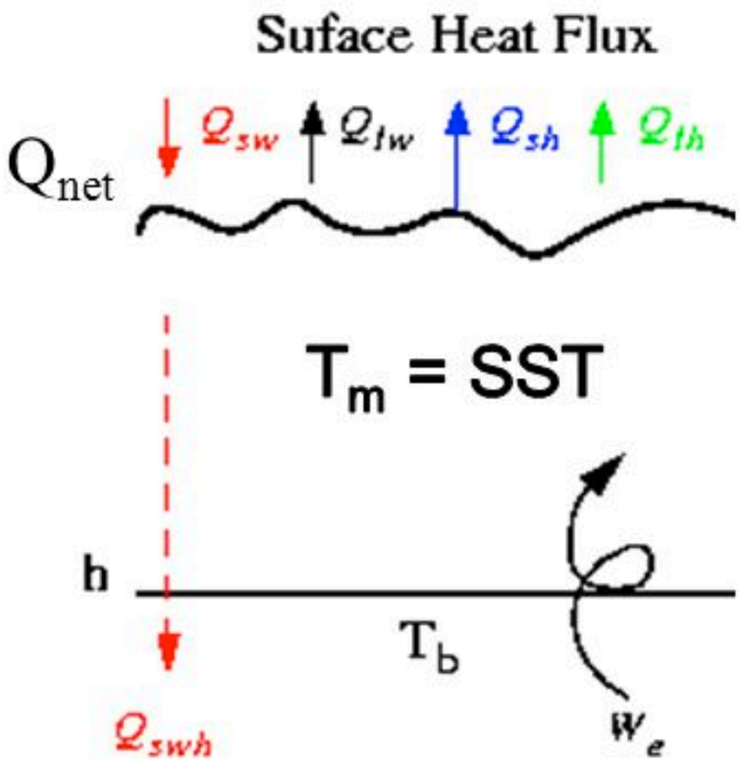


Sensible, Latent, Longwave, Shortwave

Surface Heat Fluxes

$$\frac{\partial T_m}{\partial t} = \frac{Q_{net}}{\rho c h} + \frac{W + W_e}{h}(T_b - T_m)$$

T_b = Reference Temperature



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