where σ is a nondimensional vertical coordinate ranging from 0 at the surface to 1 at the base of the surface boundary layer (at h_{sbl}). The subscript f refers to either momentum or potential density in this study.

[21] Under neutral surface forcing conditions (no heat or salinity fluxes), h_{sbl} is calculated as the minimum of the Ekman depth, estimated as,

$$h_e = 0.7u_s/f \tag{16}$$

(where f is the Coriolis parameter and u_b^* is the bottom friction velocity) and the shallowest depth at which a critical bulk Richardson number (Ri_c) is reached (set here to 0.3). The bulk Richardson number, Ri_b is calculated as

$$Ri_b(z) = \frac{(B_r - B(d))d}{|V_r - V(d)|^2 + V_q{}^2(d)} \tag{17}$$

where B is the buoyancy, V is horizontal velocity and d is distance from the surface. The r subscript refers to the value the field has at a near-surface reference depth, which here is specified as the top model grid level. V_q is an estimate of the turbulent velocity contribution to velocity shear and is calculated as

$$V_t^2(d) = \frac{C_v(-\beta_T)^{1/2}}{Ri_c}(c_s\epsilon)^{-1/2}dNu_s^*, \tag{18}$$

where $C_v = 1.6$, $c_s = -98.96$, $\epsilon = 0.1$ and $\beta_t = 0.2$.

[22] To estimate w_x throughout the boundary layer, surface layer similarity theory is utilized. Following an argument by *Troen and Mahrt* [1986], *Large et al.* [1994] estimate the velocity scale as

$$w_f = \frac{\kappa u_s^*}{\phi_f(\zeta)} \tag{19}$$

where ϕ_f is a nondimensional flux profile associated with the stability parameter ζ, which varies on the basis of the stability of the boundary layer forcing. In the neutral forcing case it is identically 1 and $w_f = \kappa u_s^*$.

[23] The nondimensional 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-Obukov similarity theory approaching the surface. This function is defined as

$$G(\sigma) = a_0 + a_1\sigma + a_2\sigma^2 + a_3\sigma^3 \tag{20}$$

with coefficients a_0 and a_1 specified to match boundary conditions at the surface and a_2 and a_3 determined to smoothly blend mixing within the boundary layer with the interior:

$$a_o = 0 \tag{21}$$

$$a_1 = 1 \tag{22}$$

$$a_2 = -2 + 3\frac{\nu_x(h_{sbl})}{h_{sbl}w_x(1)} + \frac{\partial_x\nu_x(h_{sbl})}{w_x(1)} + \frac{\nu_x(h_{sbl})\partial_\sigma w_x(1)}{h_{sbl}w_x^2(1)} \tag{23}$$

$$a_3 = 1 - 2\frac{\nu_x(h_{sbl})}{h_{sbl}w_x(1)} - \frac{\partial_x\nu_x(h_{sbl})}{w_x(1)} - \frac{\nu_x(h_{sbl})\partial_\sigma w_x(1)}{h_{sbl}w_x^2(1)}. \tag{24}$$

Here, $\nu_x(h_{sbl})$ is the viscosity calculated by the interior parameterization at the boundary layer depth. (Note that ν will be used to refer to an estimate by the interior parameterization and K_ρ will refer to one associated with the boundary layer estimate.)

[24] The interior scheme of KPP gives estimates of the viscosity coefficient by adding the effects of shear mixing and internal wave-generated mixing (along with double-diffusive mixing, which is set to zero here). The shear mixing term is calculated using a gradient Richardson number formulation with viscosity estimated as:

$$\nu^{sh} = \begin{cases} \nu_0 & Ri_g < 0, \\ \nu_0\left[1 - \left(Ri_g/Ri_0\right)^2\right]^3 & 0 < Ri_g < Ri_0, \\ 0 & Ri_g > Ri_0 \end{cases} \tag{25}$$

where ν_0 is 5.0×10^{-3} m^2 s^{-1}, $Ri_0 = 0.7$ and Ri_g is as defined in equation (14). The turbulent Prandtl number is assumed to equal 1 for this parameterization so $\nu_\rho = \nu_M$.

[25] Internal wave-generated mixing serves as the background mixing in the KPP scheme. It is specified as a uniform value for each scalar and momentum. The values suggested by *Large et al.* [1994] for eddy diffusivity due to internal wave activity is 1.0×10^{-5} m^2 s^{-1}. It is based on the deep ocean data of *Ledwell et al.* [1993]. The internal wave generated mixing of momentum is specified as ten times this value following *Peters et al.* [1988]. These values are found to lead to unrealistically rapid broadening of the pycnocline under reasonable forcing conditions in highly stratified coastal waters. Therefore the background values for viscosity and diffusivity in this study are reduced to values identical to those used for the Mellor-Yamada scheme (1.0×10^{-5} m^2 s^{-1} for momentum and 1.0×10^{-6} m^2 s^{-1} for potential density). The contribution of internal wave generated mixing to continental shelf circulation remains an important research question.

2.2.2. Enhancement of the KPP Scheme: Appending a Bottom Boundary Layer Parameterization

[26] The KPP scheme works by matching vertical mixing rates appropriate for the surface boundary layer with ones appropriate for the interior of the flow. Thus the boundary layer is primarily determined by the surface fluxes but is also influenced by the interior. The turbulent velocity scale is solely determined by the surface forcing. The boundary layer depth is determined either by property changes relative to the surface layer or by an estimate of the Ekman layer thickness. However, the shape function that determines the profile of the mixing coefficient over the boundary layer is explicitly dependent on the vertical mixing of the interior. The value and gradient of the mixing predicted by the interior scheme at the boundary layer depth have a significant impact on mixing throughout the boundary layer. *Large et al.* [1994] justify this by referring to atmospheric boundary layer work by *Kurzeja et al.* [1991] and *Kim and Mahrt* [1992].

[27] Although the interior mixing mechanisms *Large et al.* [1994] suggested may be quite appropriate for the deep ocean, they fail to appropriately represent mixing near the bottom boundary and, consequently, are inadequate for application on a shallow continental shelf. When an