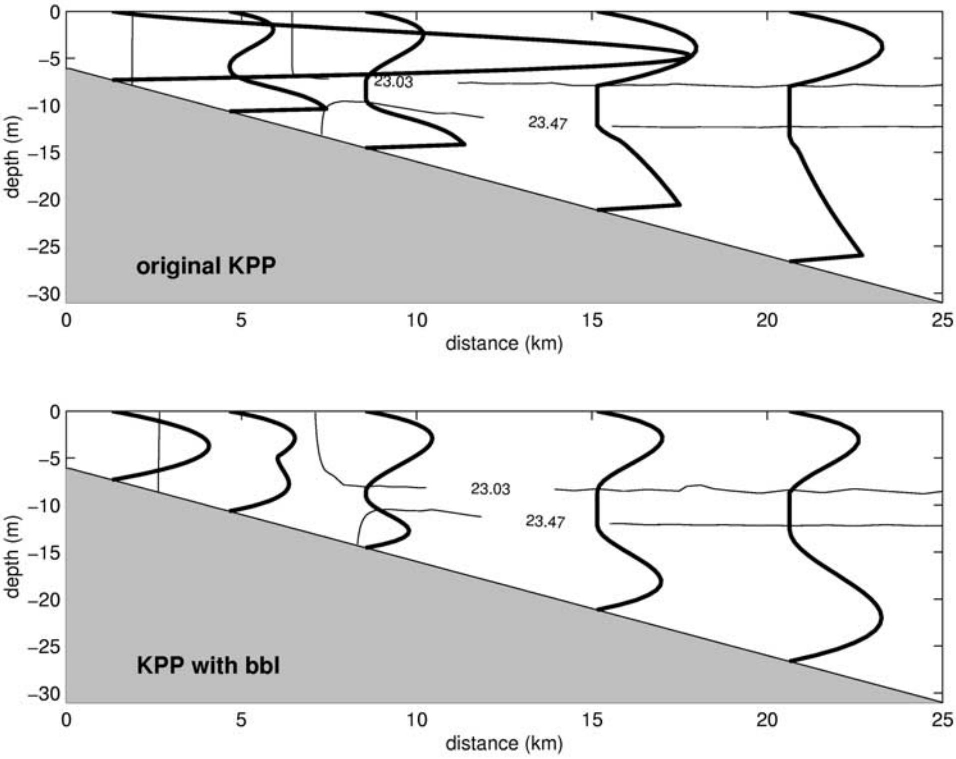

Figure 1. Profiles of vertical viscosity coefficient at day 2 of upwelling simulations with the original KPP scheme and a version that has been appended to include a representation of the bottom boundary layer. Density contours are also drawn to delineate the pycnocline.

adequately strong velocity shear exists near the bottom boundary, the gradient Richardson number-based, shear-generated mixing term of KPP will predict high levels of mixing. However, the formulation does not associate mixing intensity with a length scale to account for proximity to the boundary. If the bottom sheared flow is isolated from the surface boundary layer, a region of intense mixing will form which disobeys boundary layer similarity theory. If the surface boundary layer extends near to the bottom of the domain, as it can in shallow water, both the magnitude and the gradient of the mixing coefficients used to estimate the shape function throughout the water column will be unrealistic. Figure 1 shows several profiles of vertical viscosity over a gradually sloping continental shelf during an upwelling simulation using the original KPP scheme and the modified scheme to be discussed below. The viscosity profiles with the original scheme show gross overestimates in the well-mixed water column nearshore and unreasonable representation of the bottom boundary layer across the shelf. These problems arise primarily because the estimate of ν at the bottom interior grid point ($k = 1$) approaches the maximum allowable by the shear generated mixing scheme 0.005 $\mathrm{m}^2\ \mathrm{s}^{-1}$, while the mixing coefficient at the ocean floor is set to zero (leading to large $\partial_z \nu$ there).

[28] To alleviate this situation, we append a bottom boundary layer approximation following the KPP surface boundary layer representation. As was the case for the surface boundary layer we determine a mixing profile for the bottom boundary layer constrained by a requirement of matching Monin-Obukov similarity scaling as the boundary is approached. Thus viscosity in the bottom constant stress layer should reduce to

$$K = \kappa u_b^* z, \tag{26}$$

where u_b^* is the bottom friction velocity. Only the case of zero bottom buoyancy flux is considered here as this is usually appropriate. The turbulent velocity scale for the bottom boundary layer reduces to $w_b^* = \kappa u_b^*$. The bottom boundary layer depth is determined as it is for the surface layer using an Ekman layer depth estimate and a bulk Richardson number criteria. The bottom friction velocity and reference velocity and buoyancy fields are obtained using the model bottom u, v and ρ grid points.

[29] The bottom boundary layer estimate can connect with the surface and interior parameterizations in three ways.

[30] 1. If the bottom boundary layer does not extend into the surface boundary layer then the bbl parameterization simply matches with the interior just as the surface boundary layer scheme does.

[31] 2. If it extends over the entire depth of the water column (or the surface boundary layer does), the shape function is specified to properly match with neutral law-of-the-wall behavior ($\partial_z K_v = \kappa u^*$), at the top and bottom boundaries.

[32] 3. When surface and bottom boundary layers intersect but do not fully overlap, vertical mixing due to the effects of each must be matched. Vertical mixing in the