Supplementary Materials

The governing equations for the ZC ocean model consists of the reduced-gravity model for the vertical averaged ocean current (u,v) above the thermocline together with an imbedded constant depth mixed layer. The reduced-gravity model is written as follows:

$$u_t - \beta_0 y v = -g' h_x + \tau_x / \rho H \qquad \text{(S1)}$$

$$\beta_0 y u = -g' h_y + \tau_y / \rho H \qquad \text{(S2)}$$

$$h_t + H\left(u_x + v_y\right) = 0 \qquad \text{(S3)}$$

$$\mathrm{Hu} = H_1 u_1 + H_2 u_2 \qquad \text{(S4)}$$

The subscripts 1, 2 refer to the current in the mixed layer and the underlying layer, respectively. ρ is ocean density, and τ is the surface wind stress, H and H1 refer to the climate mean thermocline depth and a constant mixed layer depth. This reduced-gravity model equation is the same as that in ZC except the weak linear friction is ignored for consistency as we used the model code of *McGregor et al.* [2007] for simulations of wave upwelling.

The equations governing the shear (with subscripts) between layers 1, 2 are:

$$r_s u_s - \beta_0 y u_s = \tau_x / \rho H_1 \qquad \text{(S5)}$$

$$r_s v_s - \beta_0 y v_s = \tau_y / \rho H_1 \qquad \text{(S6)}$$

$$\boldsymbol{u_s} = \boldsymbol{u_1} - \boldsymbol{u_2} \qquad \text{(S7)}$$

Here a strong momentum mixing between the two layers is represented by a strong frictional coefficient $r_s=(2day)^{-1}$.

The upwelling velocity can then be derived as:

$$W_1 = H_1\left[(u_1)_x + (v_1)_y\right]$$

$$= \frac{H_1}{H} \cdot H\left[u_x + v_y\right] + \frac{H_2}{H} \cdot H_1[(u_s)_x + (v_s)_y]$$

$$= \frac{H_1}{H} \cdot W_h + (1 - \frac{H_1}{H}) \cdot W_e \quad \text{(S8)}$$

In this paper, instead of assuming H as a constant, we take the zonal variations in the climate mean of thermocline depth into consideration and thus define the vertical velocity at 50 meter as

$$W \ = \left(1 - R(x)\right) \cdot W_e + R(x) \cdot W_h \quad \text{(S9)}$$

Here, R(x) represents the weighting function which depends on longitude (Figure S1). The Ekman pumping upwelling is defined the same way as in ZC as follows:

$$w_e = H_1\left[(u_s)_x + (v_s)_y\right] \quad \text{(S10)}$$

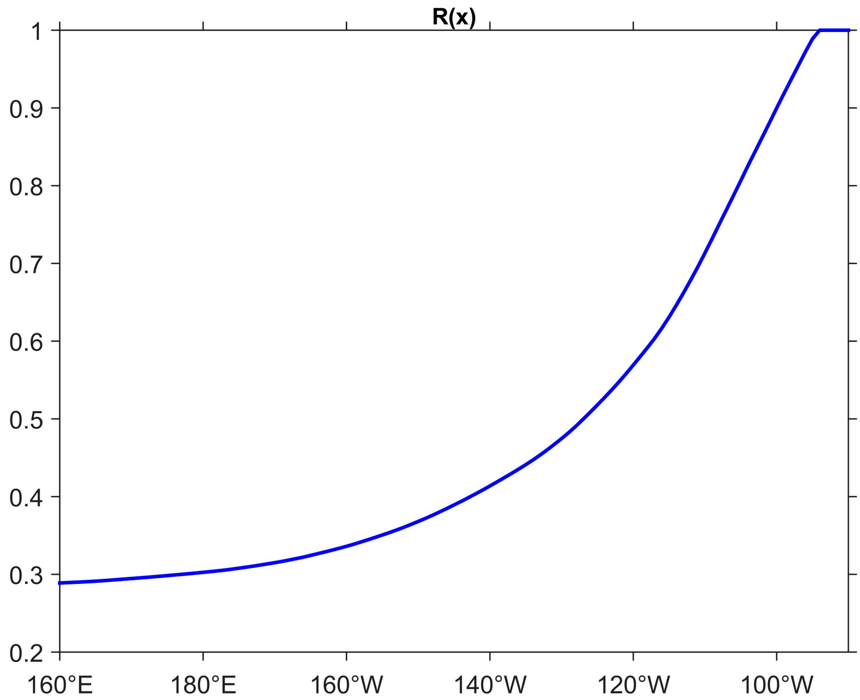

Figure S1. The weighting function R(x) used to estimate the equatorial Pacific upwelling annual cycle.