Supporting Information for

# $^{231}$Pa and $^{230}$Th in the ocean model of the Community Earth System Model (CESM1.3)

1. Vertical differentiation scheme in calculating the reversible scavenging term: $w_S \frac{\partial A_p}{\partial z}$

In the calculation of $w_S \frac{\partial A_p}{\partial z}$, we consider downward as positive ($w_S$ is positive). $w_S \frac{\partial A_p}{\partial z}$ can be calculated by Eq.(S1). Detailed notations are illustrated in Fig.S1.

$$w_S \frac{\partial A_p}{\partial z}(k) = w_S \frac{A_p u(k+1) - A_p u(k)}{dz(k)} \quad \text{(S1)}$$

$A_p u$, which is the particulate isotope activity at the upper bound of the grid box, can be calculated by Eq. (S2). For the surface layer ($A_p u(1)$), we assume the particulate isotope activity at surface is 0, which is true as there is no surface flux for calcite, opal and POC. For layers between the surface and the bottom, we use liner interpolation. For the bottom layer, we assume $A_p u(kmt+1)$, which is the particulate isotope activity at the lower bound of the bottom cell, equals particulate isotope activity at the center of the bottom cell ($A_p(kmt)$). This is a reasonable assumption, as the vertical gradient in the abyssal is very small.

$$\begin{aligned} &A_p u(1) = 0 \\ &A_p u(k) = A_p(k-1) + \frac{A_p(k) - A_p(k-1)}{dzw(k-1)} \times \frac{dz(k-1)}{2} \qquad (1 < k \le kmt) \\ &A_p u(kmt+1) = A_p(kmt) \end{aligned} \quad \text{(S2)}$$

Under this vertical differentiation scheme, if we do vertical integration of $w_S \frac{\partial A_p}{\partial z}$, we will get $w_S A_p(kmt)$, which is the column removal rate of isotope activity and this simulates the process of sedimentation. Therefore, we use $[^{231}\text{Pa}]_p$ and $[^{230}\text{Th}]_p$ in the bottom grid box to calculate sediment $^{231}$Pa/$^{230}$Th activity ratio in our model.

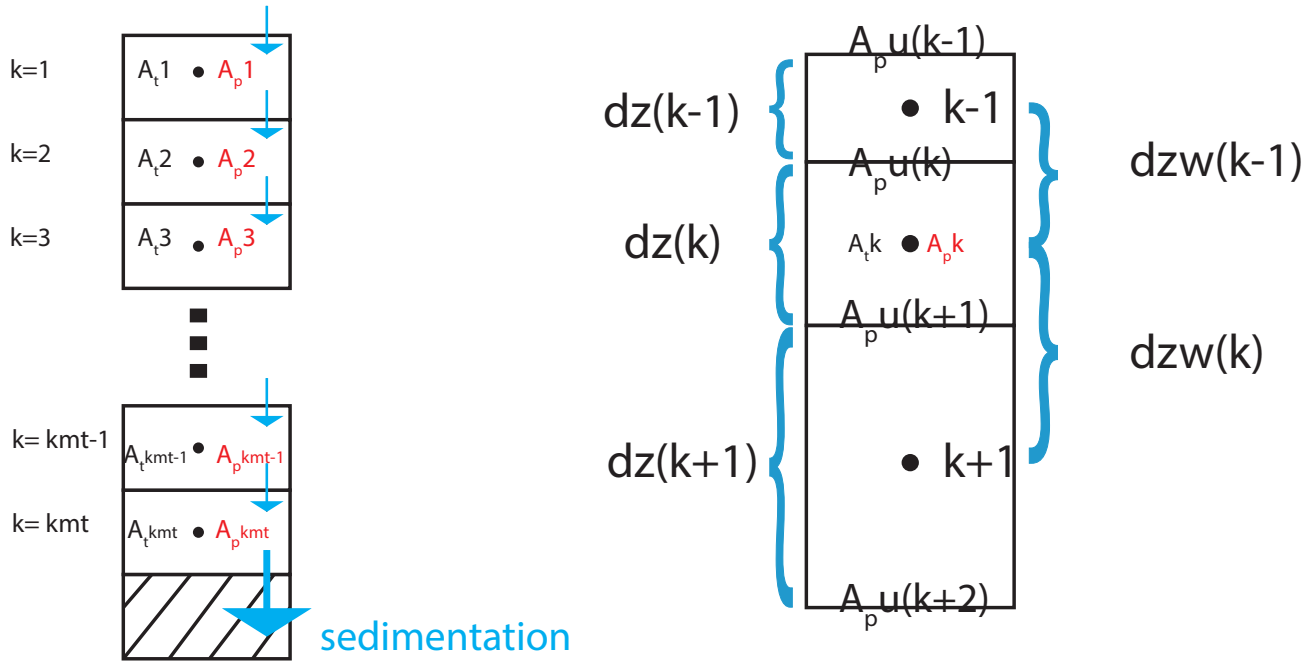


Figure S1. Schematic of model grid. k is the vertical layer. kmt is the maximum vertical layer at this location (k=kmt is the bottom layer). $A_t$ is the total isotope activity. $A_p$ is particulate isotope activity. $A_t$ and $A_p$ are located at the center of the grid box. $A_p u$ is the $A_p$ value at the upper bound of the grid box. dz(k) is the thickness of the layer k. dzw(k) is the distance from the center of layer k to the center of layer k+1.

| **Regression Coefficient** | **CTRL** | **EXP_1** | **EXP_2** |
|---|---|---|---|
| **Global** | 0.2 | 0.47 | 0 |
| **Atlantic** | 0.86 | 0.45 | 0.52 |
| **Pacific** | 0.16 | 0.79 | -0.08 |
| **SO** | 0.18 | 0.38 | 0.04 |

Tabel S1. Linear regression coefficient between global and regional sediment $^{231}Pa/^{230}Th$ in model and observation.

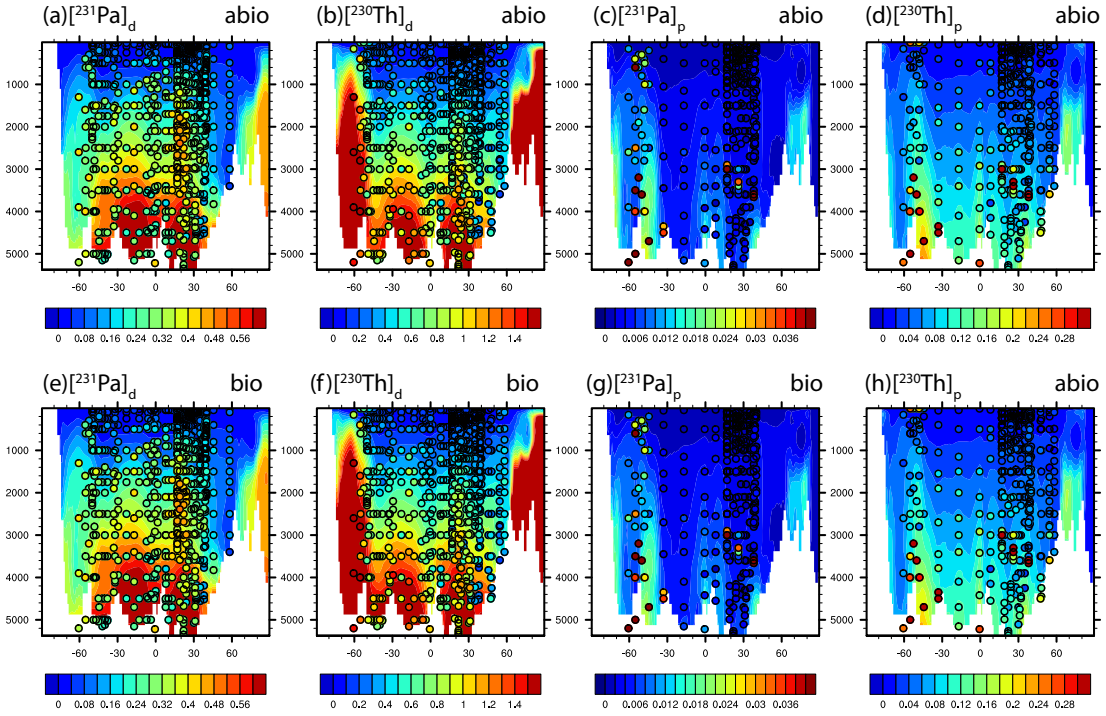


Figure S3. Atlantic zonal mean dissolved and particulate $^{231}$Pa and $^{230}$Th in CTRL for both abiotic and biotic (unit: dpm/m$^3$). Abiotic: (a) dissolved $^{231}$Pa; (b) dissolved $^{230}$Th; (c) particulate $^{231}$Pa; (d) particulate $^{230}$Th. Biotic: (e) dissolved $^{231}$Pa; (f) dissolved $^{230}$Th; (g) particulate $^{231}$Pa; (h) particulate $^{230}$Th.

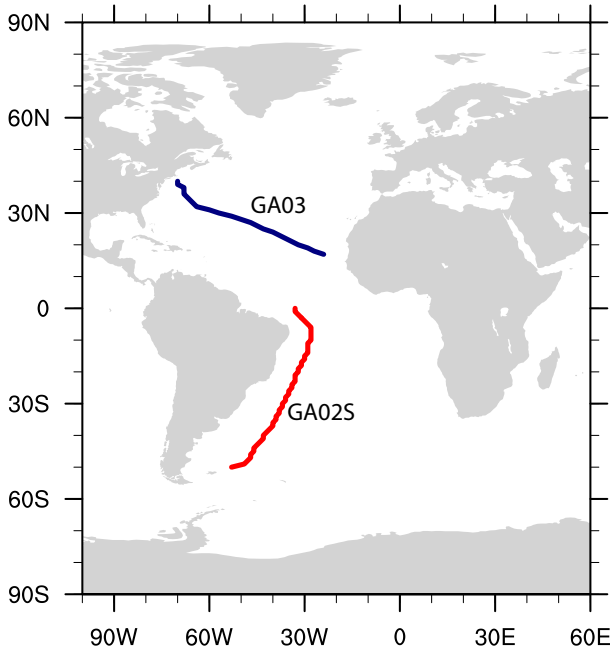


Figure S4. GEOTRACES transect GA03 (navy) (Hayes et al., 2015) and GA02S (red) (Deng et al., 2014) in the Atlantic.