Supplementary Material

1 Global Averaging of Martin's b parameter

Here we describe the calculation of a global mean from samples of spatially variable b. Figure 6 in the manuscript shows that when CO_2 is plotted against the global mean b of the Latin hypercube samples, there is a constant offset versus runs where b is varied uniformly. We suggest that this offset is a function of a non-linear relationship between b and the amount of organic carbon reaching the ocean interior. This is demonstrated by expressing b as an e-folding depth (the depth at which the proportion of organic matter that has remineralisation = $\frac{1}{e} \approx 0.63$). This is achieved by rearranging the Martin curve equation:

$$F_z = F_{z_0} \left(\frac{z}{z_0} \right)^{-b} \quad (1)$$

for depth (z) when $\dfrac{F_z}{F_{z_0}} = \dfrac{1}{e}$:

$$z = \sqrt[-b]{\frac{F_z}{F_{z_0}}} z_0 \quad (2)$$

where z_0 is the depth of the euphotic zone (here z_0=120 m), F_z is the flux of POC at depth z and F_{z0} is the flux of POC out of the euphotic zone (z_0). e-folding depths get increasingly deeper with decreasing values of b (Figure 1). For example, a change in b from 1.4 to 1.3 results in a decrease in e-folding depth of 14 m whereas a change in b from 0.4 to 0.3 results in a 1902 m. This follows from the fact that the Martin curve represents the scenario of a fixed remineralisation rate and an increasing sinking rate (Kriest and Oschlies, 2008). Therefore, when averaging spatially variable b values, larger values will have disproportionally more weight in comparison to their impact on ocean biogeochemistry.

To account for this non-linear effect on biogeochemistry, we alternatively calculate the global mean of each Latin hypercube ensemble experiment when converted to e-folding depths. Because of the non-linear relationship between b and e-folding depths, an arithmetic mean is unsuitable (e.g., Figure 3). We alternatively calculate an area-weighted geometric-weighted mean and convert this back to a value of b:

An alternative approach to calculating a global mean is to calculate a set of weights based on e-folding depths. However, the calculation of these weights is not straightforward. Alternatively, a Latin hypercube ensemble could be samplefrom a uniform distribution of e-folding depths rather than b and parameterising remineralisation with an exponential function. However, power-law based parametersations are commonly usedn in biogeochemical models (e.g., Hülse et al., 2017) as well as in interpreting observations (Honjo et al., 2008). We note that a number of different mathematical functions, each with different mechanistic interpretations and including a power-law and exponential function, are not statistically distinguishable from each other based on existing observations (Cael and Bisson, 2018).

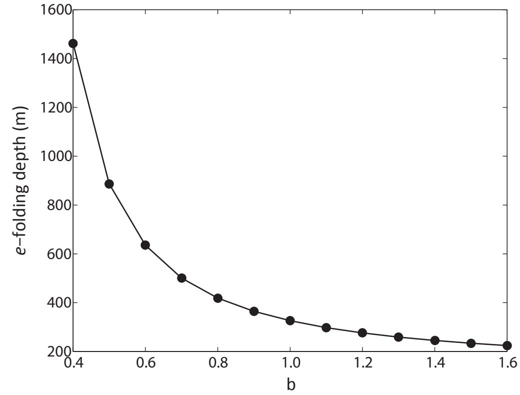

Figure 1. The *e*-folding depths (depth at which 0.63% of organic matter has been remineralised) corresponding to various Martin curve exponents. *e*-folding depths are calculated using eqn. 2.

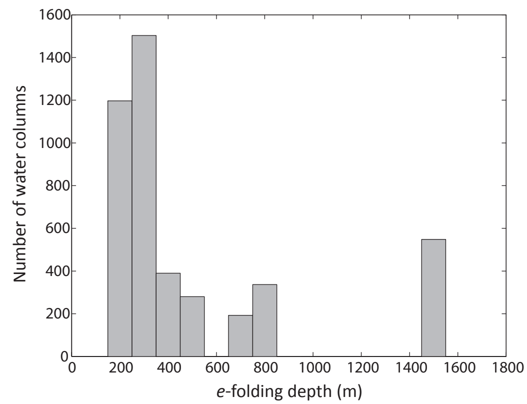

Figure 2. Histogram of *e*-folding depths for all water columns in the model, calculated from *b* values from one Latin hypercube sample using equation 2.

References

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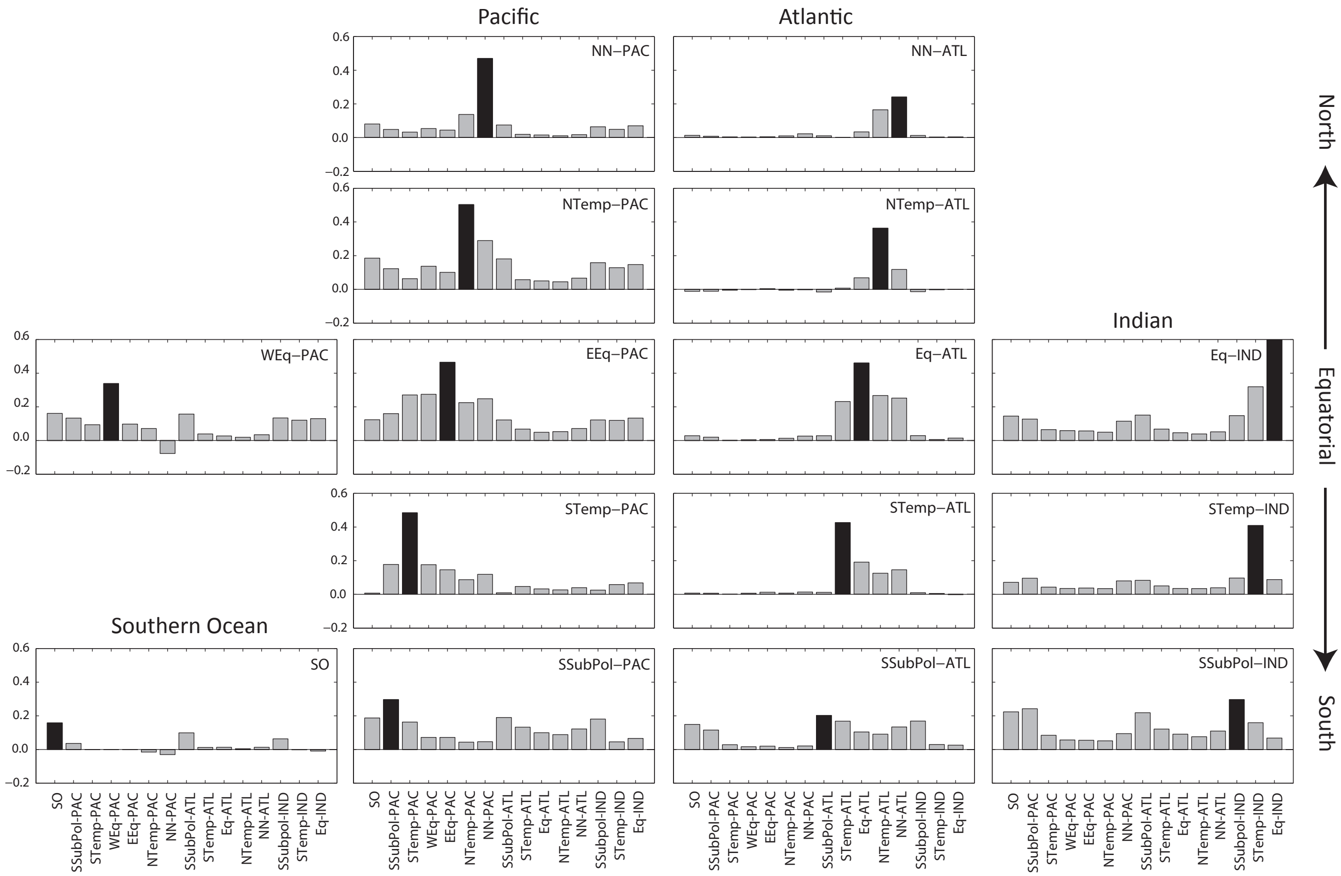

Figure 3. Normalised sensitivity of steady-state mean preformed [PO_4] from each region to regional changes in b calculated with the restoring-export scheme. Sensitivity is calculated using the same linear regression method as in Figure 3 except that preformed [PO_4] is normalised before so that sensitivity can be compared on the same scale. Bars show the magnitude and sign of sensitivity to changes in b that are local to that region (black) and in other regions (grey). Panels are arranged by basins and by latitude. The equiavlent plot for the constant-uptake scheme is found in Figure 5 of the main text.