What controls the biological pump in the ocean ?

Implications for future warming and ocean acidification

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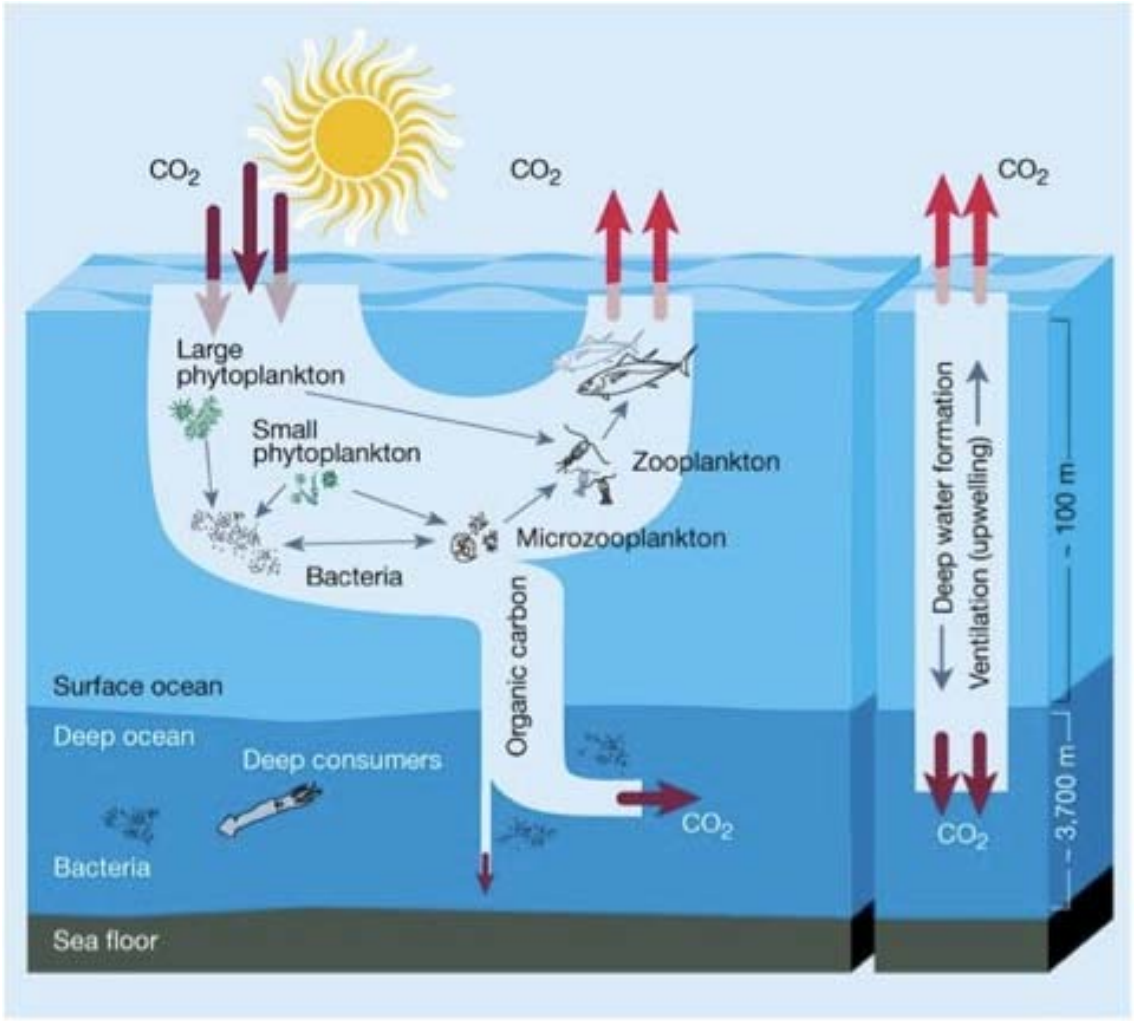
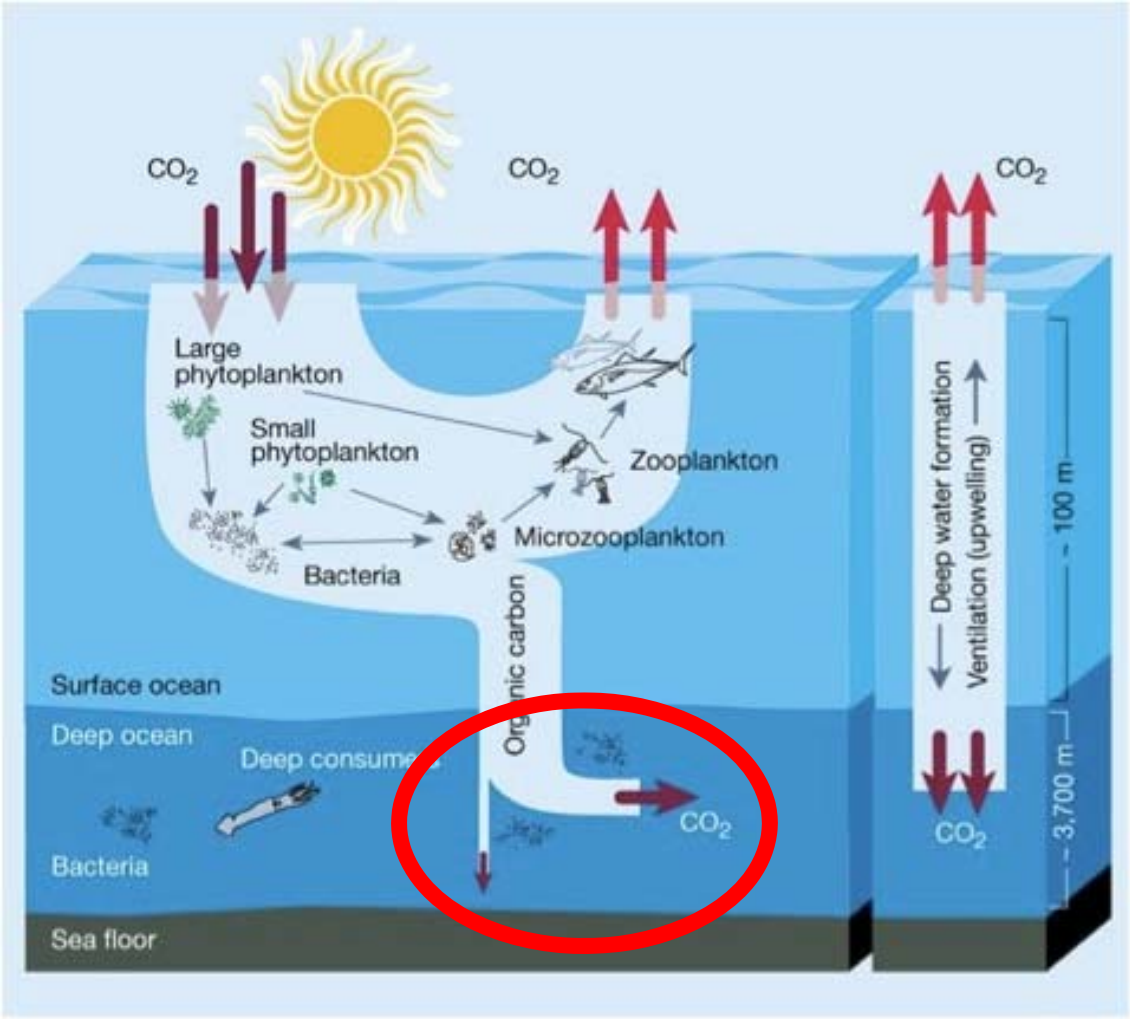
UK Ocean Acidification Research Programme

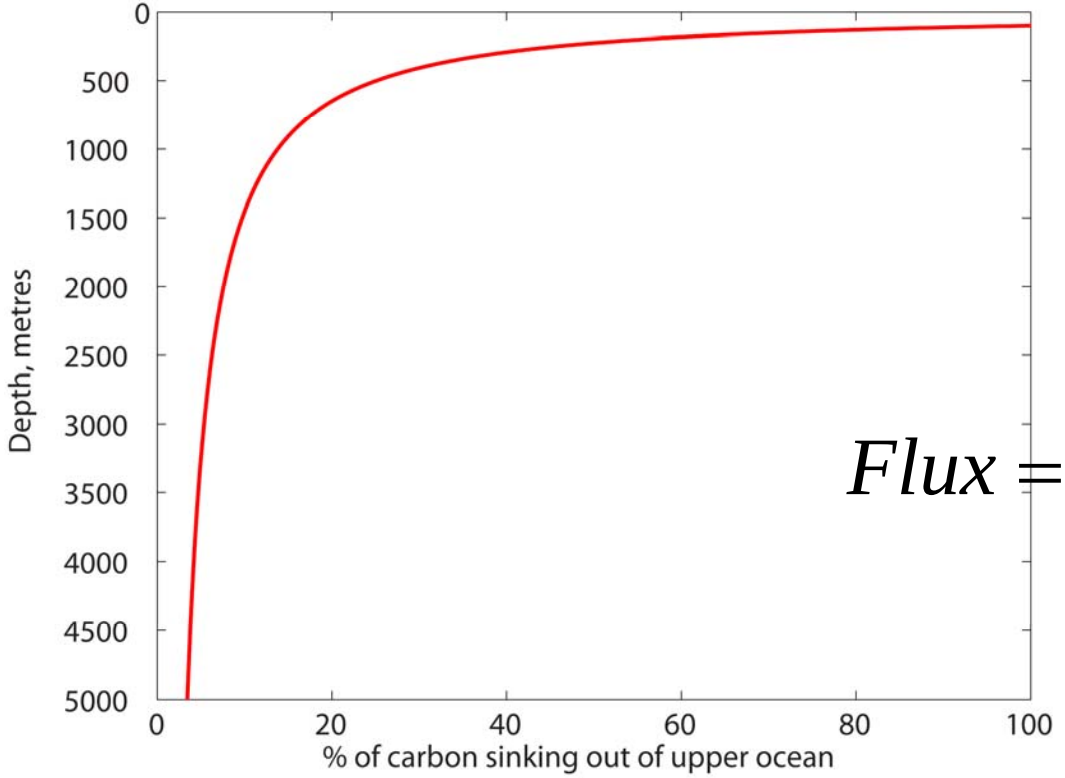
The biological pump



The biological pump



How is Organic Carbon transferred to depth?

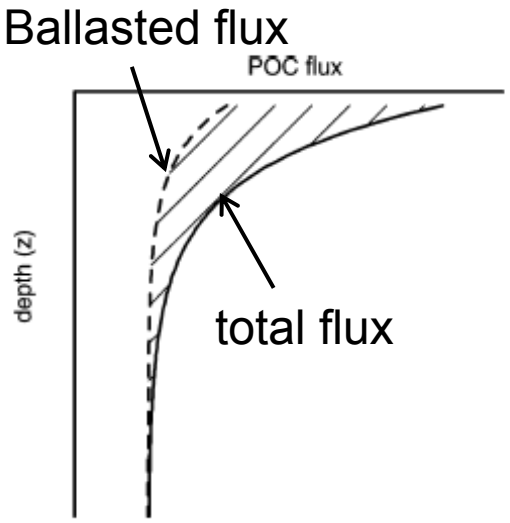


Martin et al. (1987)

$$Flux = Export \cdot \left(\frac{z}{100} \right)^{-b}$$

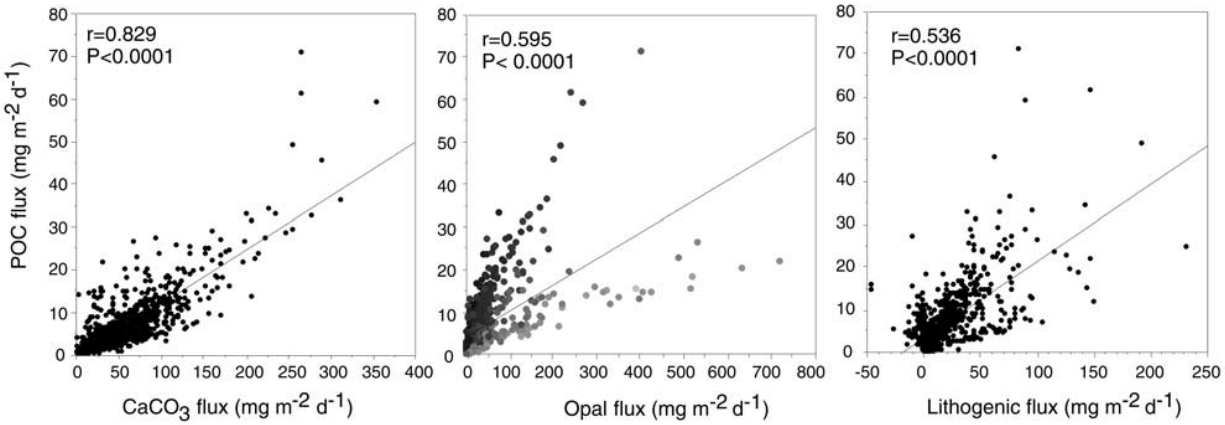
- Martin's flux curve and original *b* value based on 9 flux profiles in North Pacific; *b* =0.898
- *b* initially assumed to be constant

Ballast hypothesis



Armstrong et al. 2002

- Biominerals (particularly $CaCO_3$), increase density of sinking particles and/or provide protection against degradation



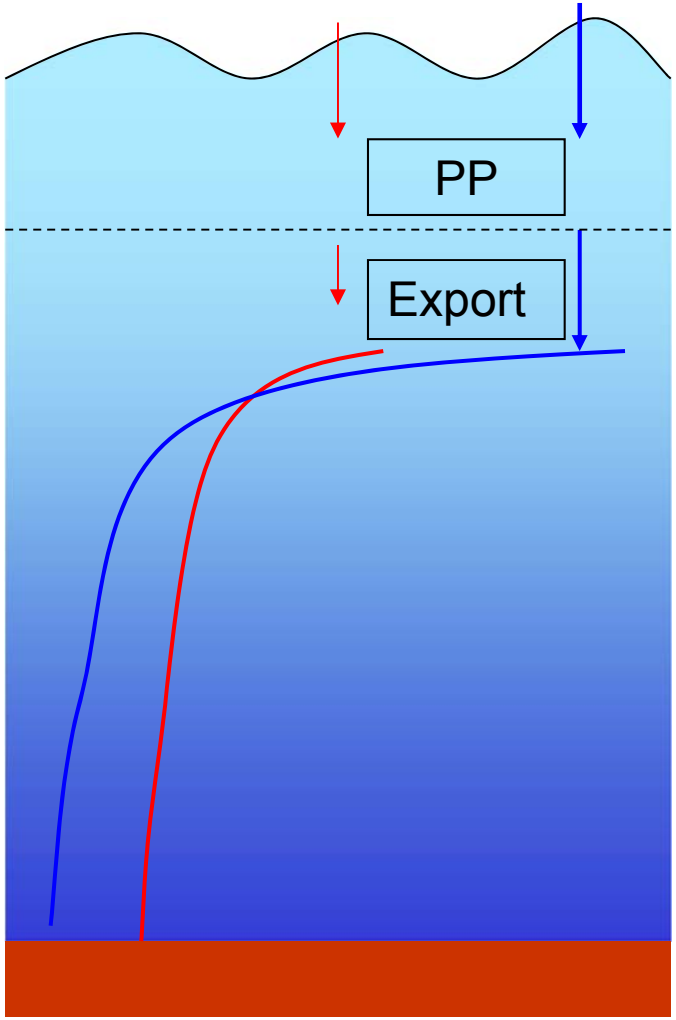
$$F_{POC} = \beta_1 \cdot F_{CaCO_3} + \beta_2 \cdot F_{opal} + \beta_3 \cdot F_{litho}$$

Klaas and Archer (2002)

POC: Particulate Organic Carbon

Ecosystem function

More C delivered to mesopelagic at high latitudes → food web structure?



High export efficiency

Low export efficiency

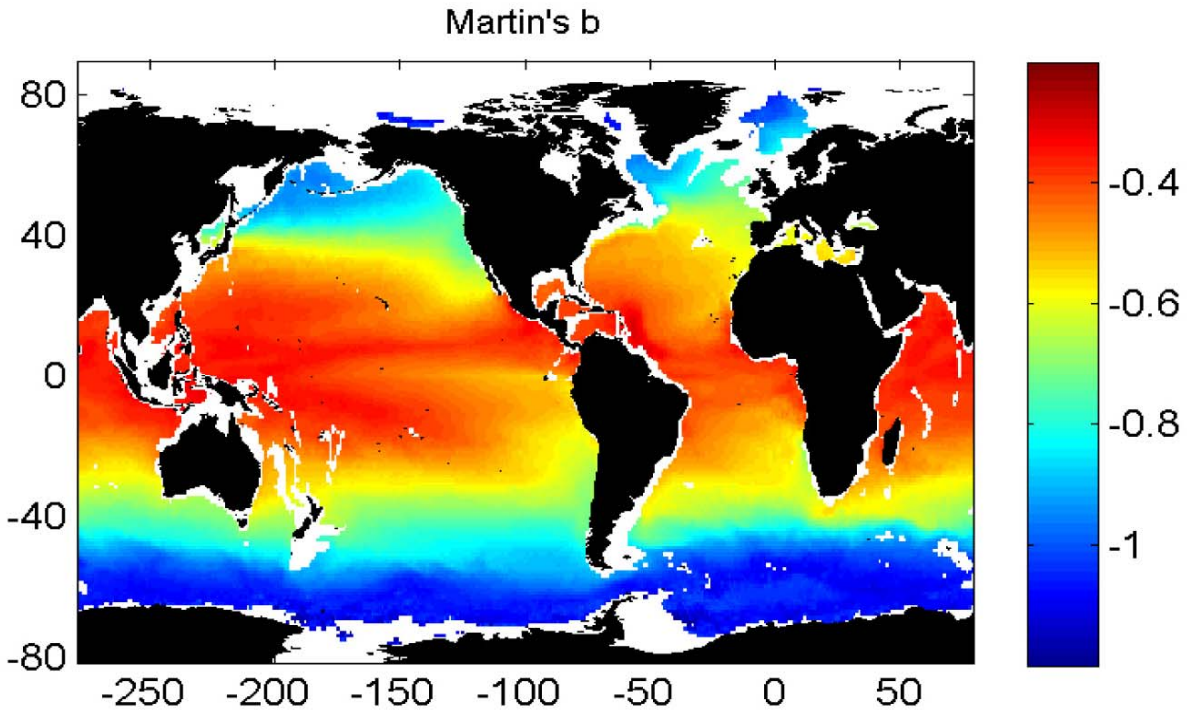
Low transfer efficiency

High transfer efficiency

Temperature dependent transfer efficiency

$$Flux = Export \cdot \left(\frac{z}{100} \right)^{-b}$$

b = (0.024 * SST) - 1.06



Henson et al., 2012

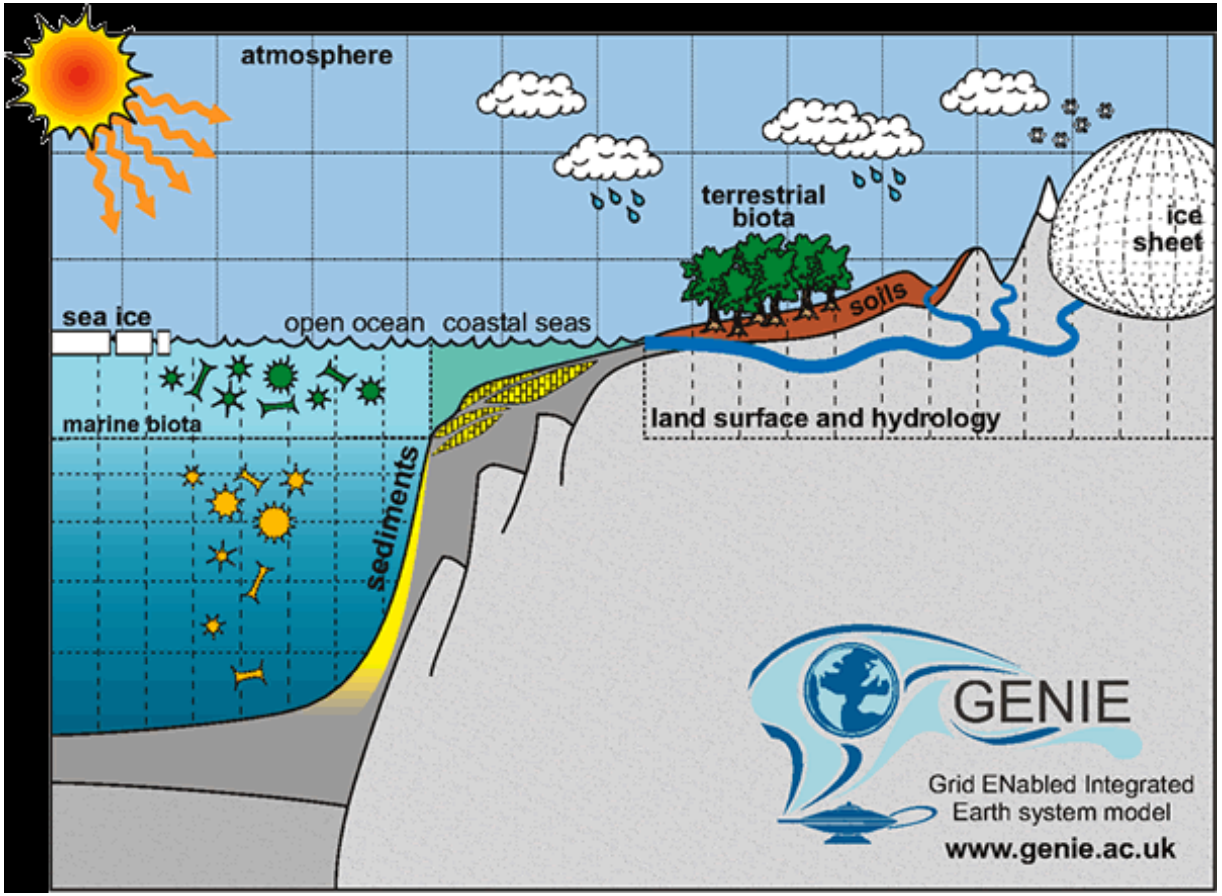
Earth System Model: cGenie

Represents biogenic biogeochemical fluxes

Organic Matter Export is a function of :

- Nutrient (PO4, Fe),
- light
- temperature
- mixed layer depth

(Death et al., in prep.) based on Doney et al., 2006



Modelling transfer efficiency

- Standard: 2 fractions of organic matter with exponential decay

  Fixed everywhere and constant through time

- Ballasting: one fraction depends on $CaCO_3$ flux

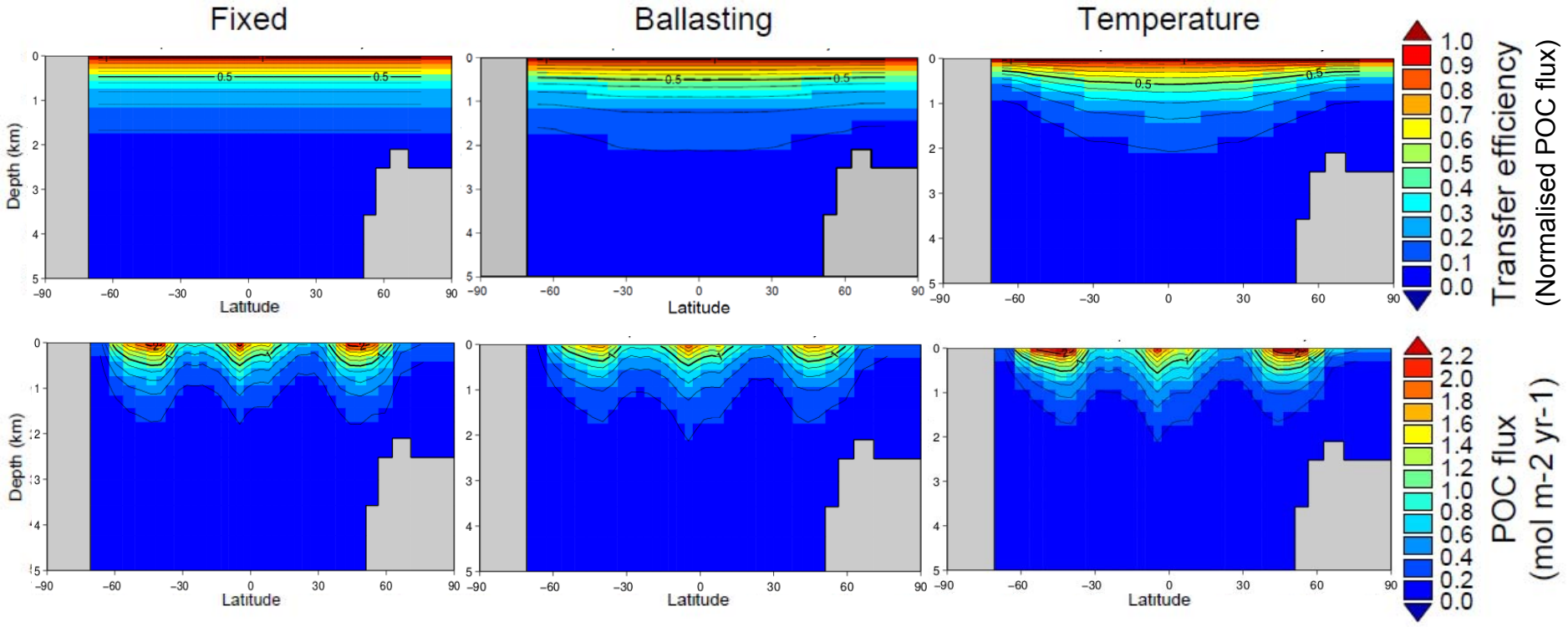
- Henson et al. (2012, GBC):

  Exponential decay dependent on sea surface temperatures

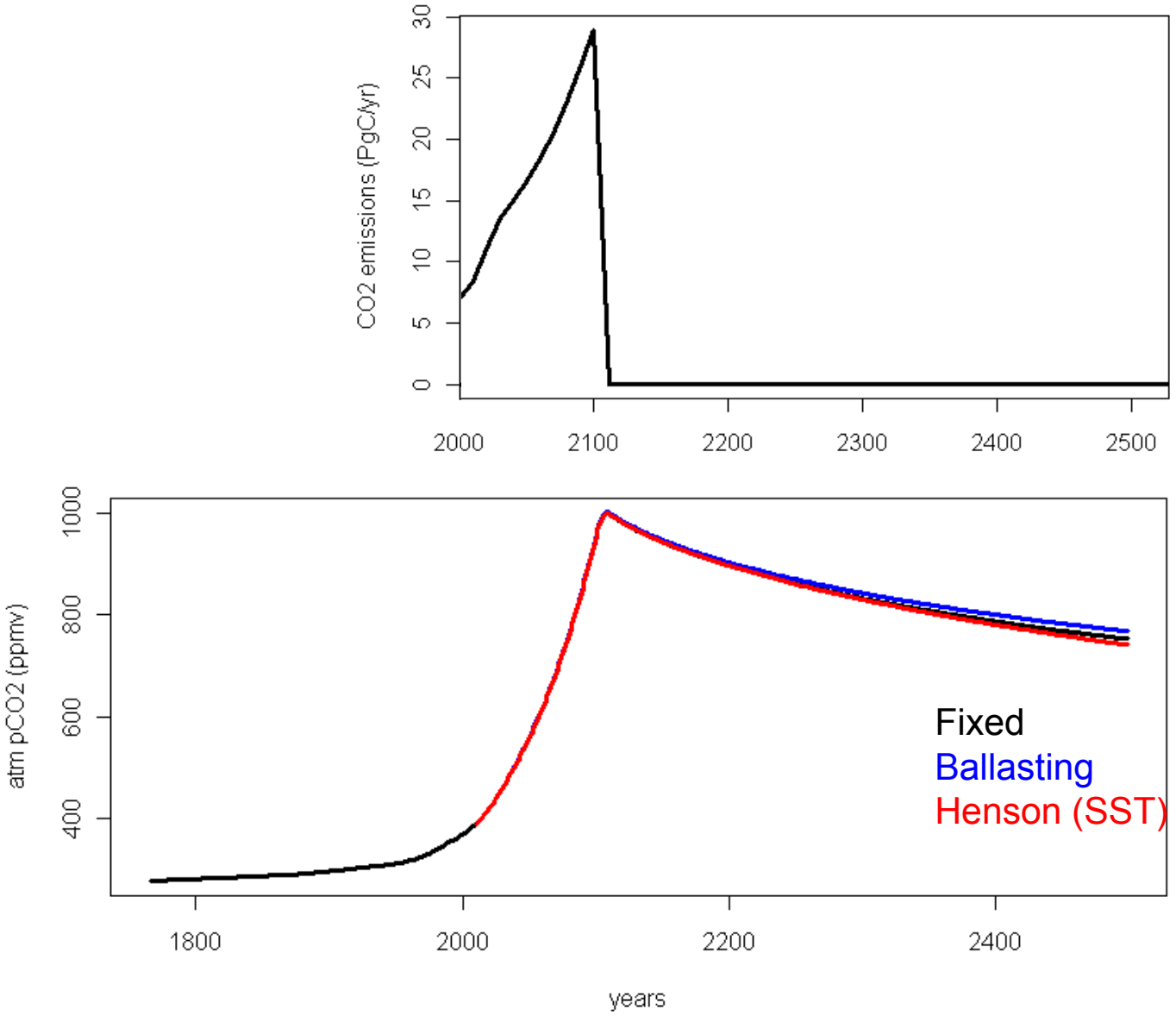
Recalibrating cGenie

- Changing the POC flux profile redistributes nutrients in the ocean
  - Need to recalibrate model
- We optimised :
  - biological uptake timescale (control on POC export)
  - remineralisation profile parameters
- Selected simulations with smallest mean squared error for 3D annual PO_4 and O_2 (World ocean atlas 2009).

Profiles of transfer efficency

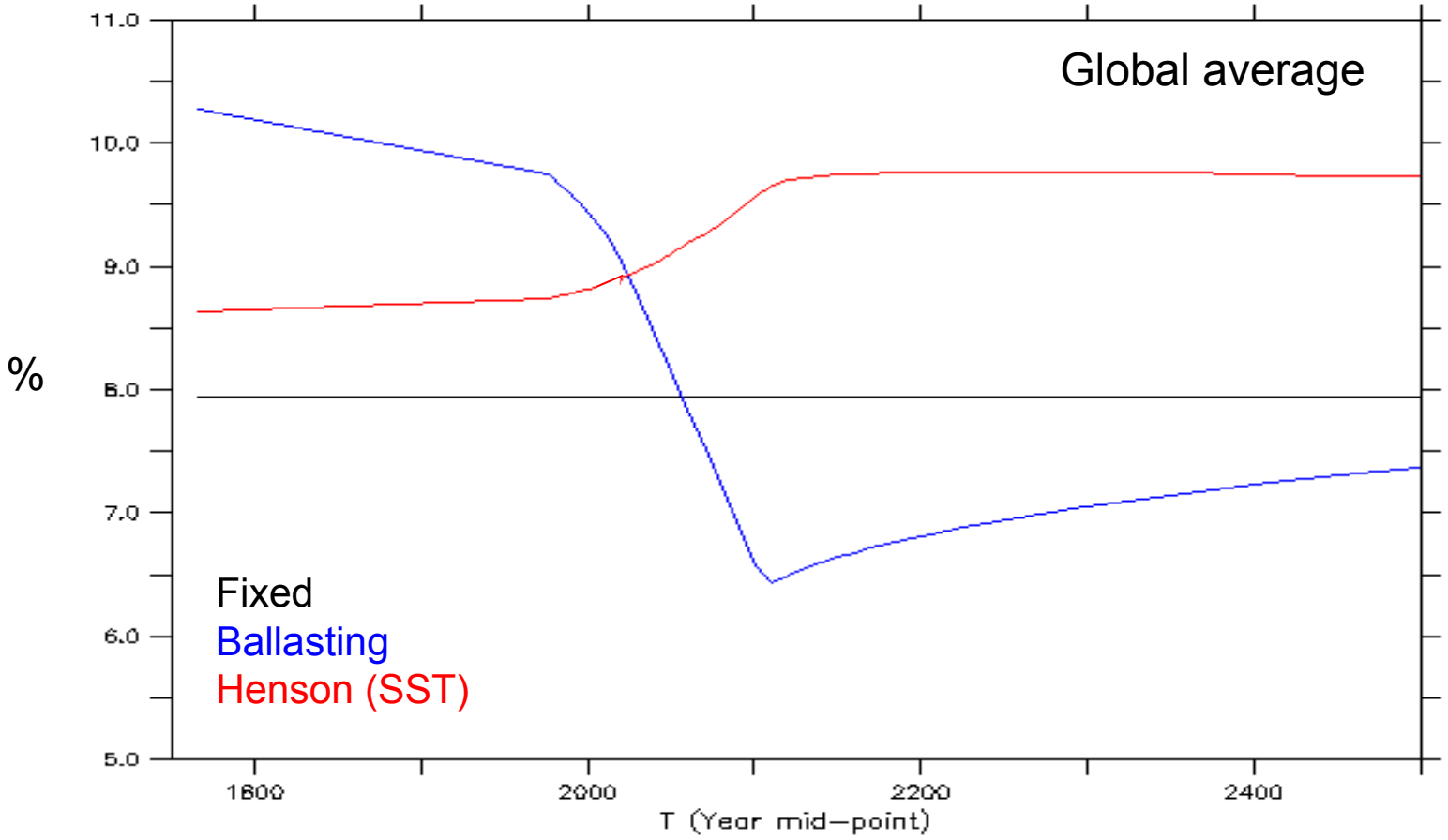


Future projections



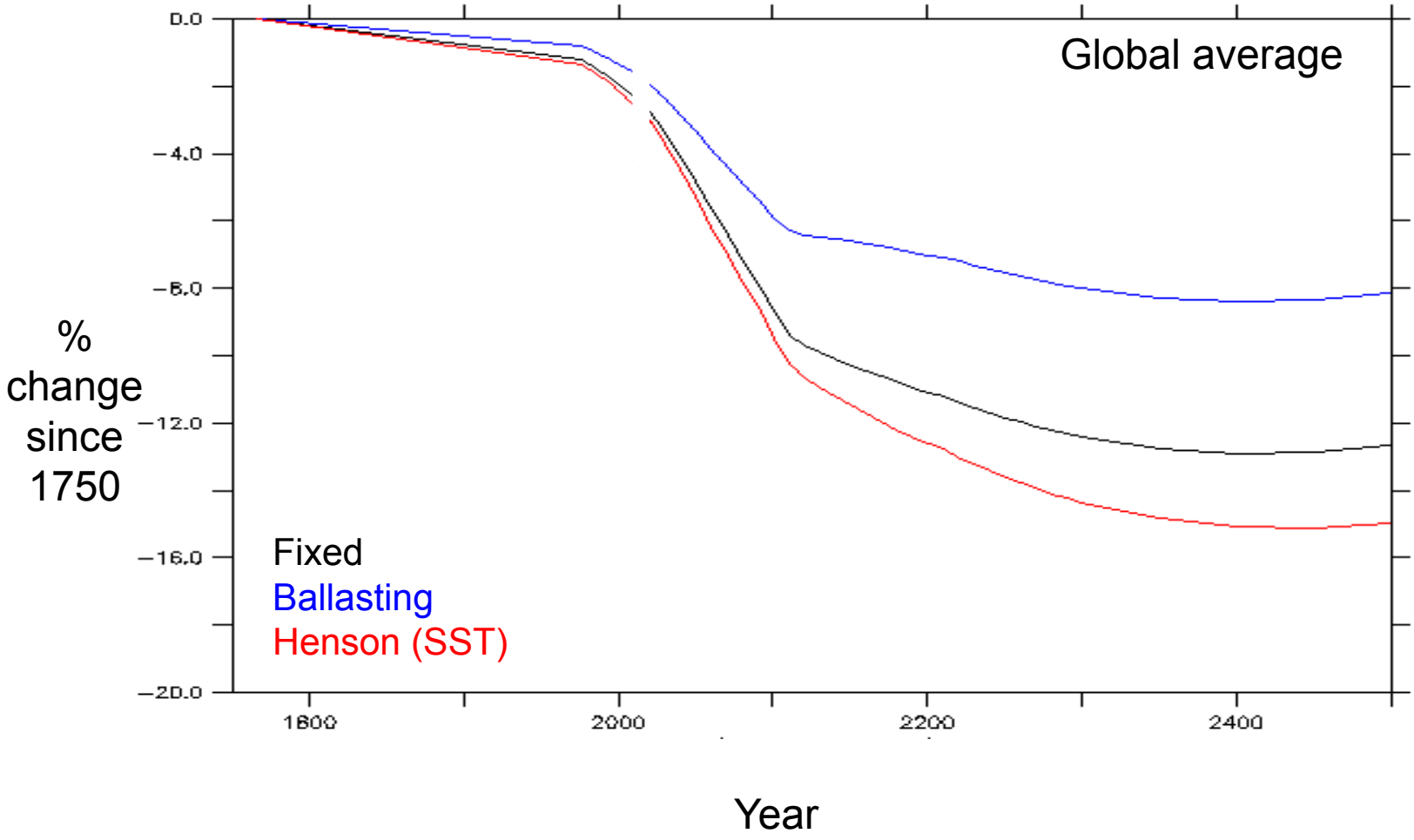
Transfer efficiency

$T_{eff}=100*F_{POC}(2000m)/Export_{POC}$; $Export_{POC}=F_{POC}(100m)$

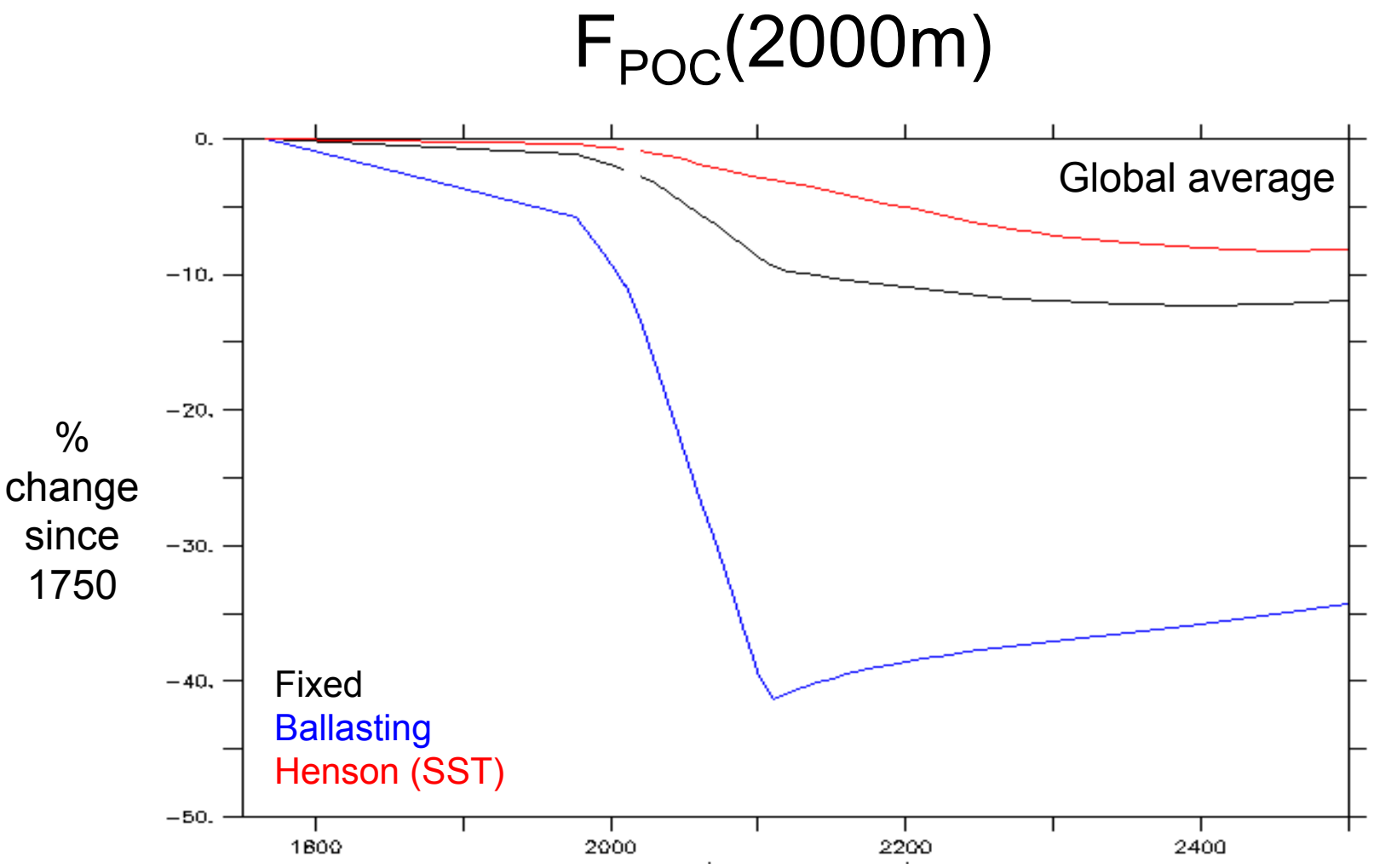


Feedback on export decrease

$Export_{POC}=F_{POC}(100m)$



Change in deep POC flux



Conclusions

- Ballast hypothesis → decrease future transfer efficiency
- SST parameterisation → increased future transfer efficiency

- Different feedback on export decrease

- Effect on Nutrient distribution and O_2 min zones, but uncertainties in biological pump:
  - Amount of export
  - Control on organic matter degradation/recycling
  - Transfer of organic matter to deep ocean

Modelling transfer efficiency

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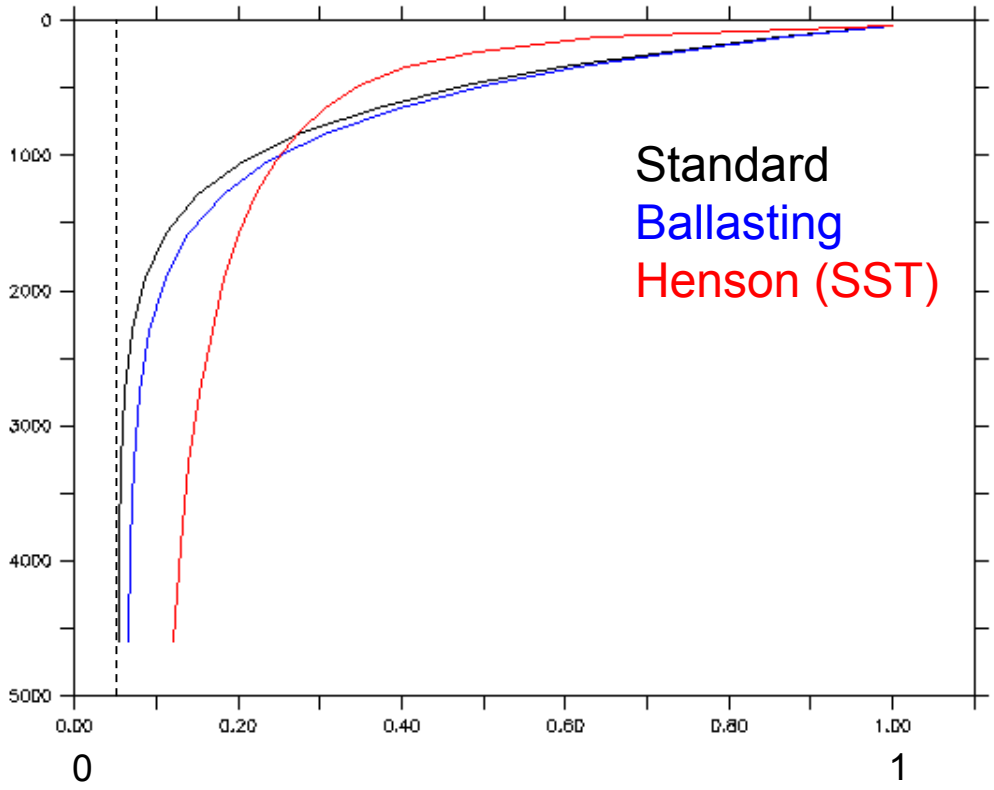
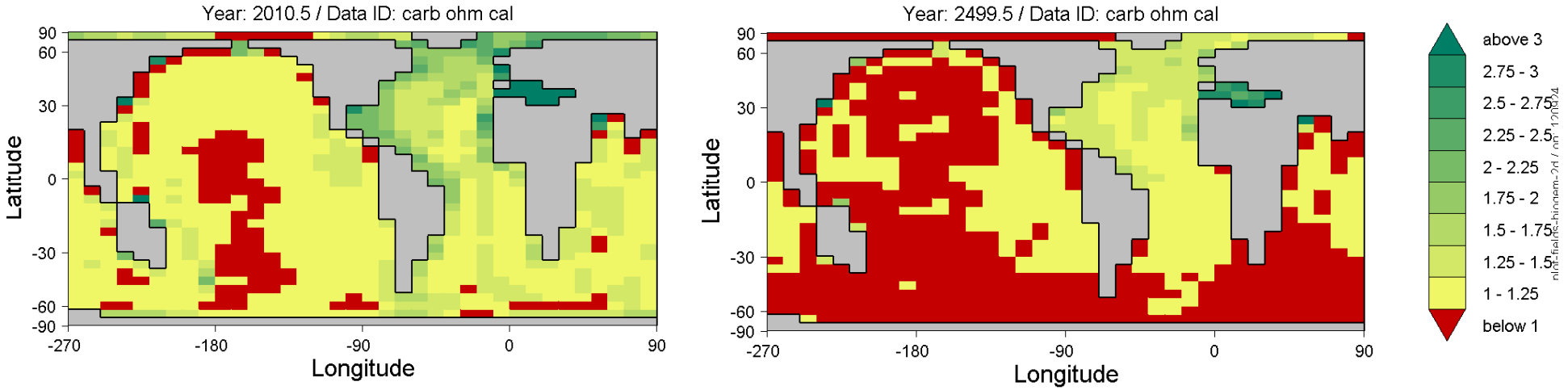
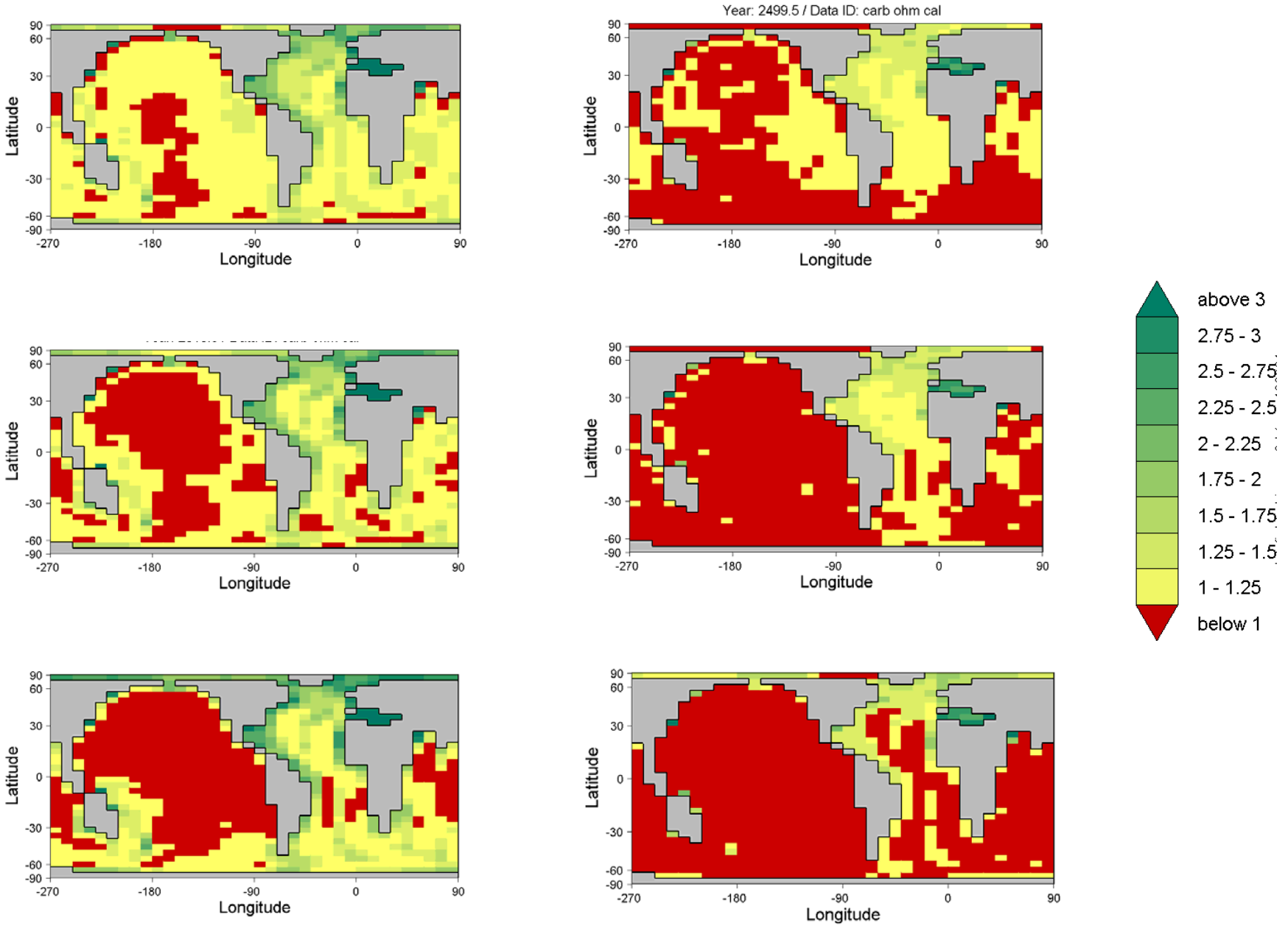


POC (particulate Organic Carbon) flux
Normalised by Export (global average)


Year: 2010.5 / Data ID: carb ohm cal
Latitude
Longitude
90
60
30
0
-30
-60
-90
-270
-180
-90
0
90
Year: 2499.5 / Data ID: carb ohm cal
Latitude
Longitude
above 3
2.75 - 3
2.5 - 2.75
2.25 - 2.5
2 - 2.25
1.75 - 2
1.5 - 1.75
1.25 - 1.5
1 - 1.25
below 1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Latitude
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90
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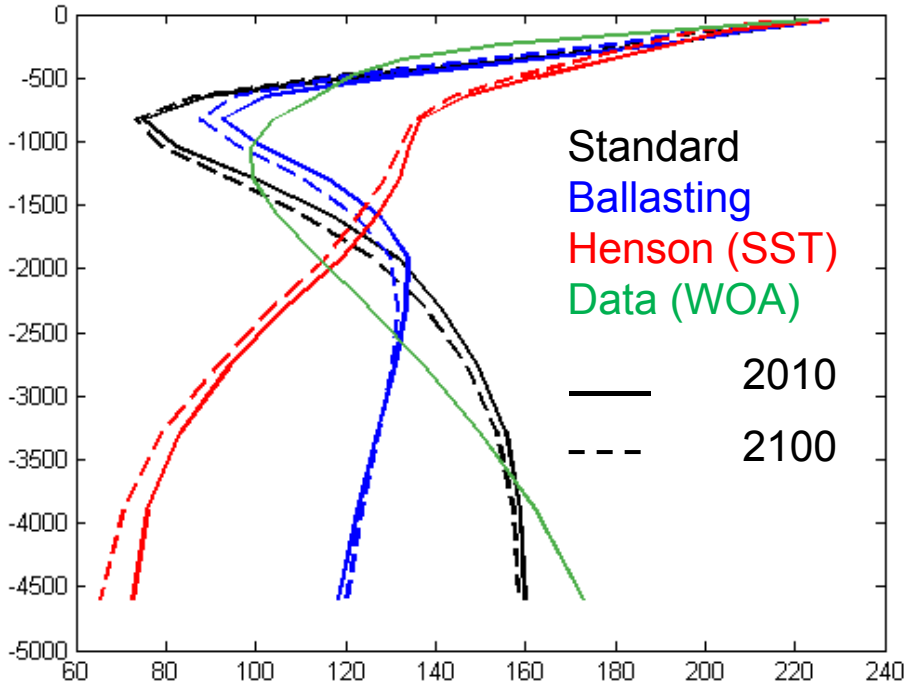
2.5 - 2.75
2.25 - 2.5
2 - 2.25
1.75 - 2
1.5 - 1.75
1.25 - 1.5
1 - 1.25
below 1

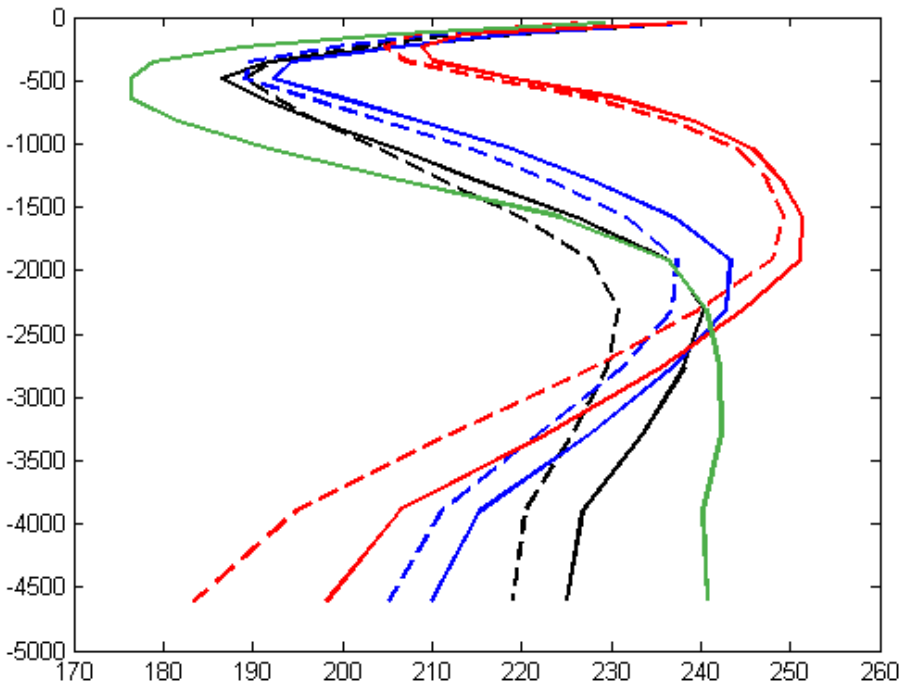
Dissolved Oxygen profiles

Pacific



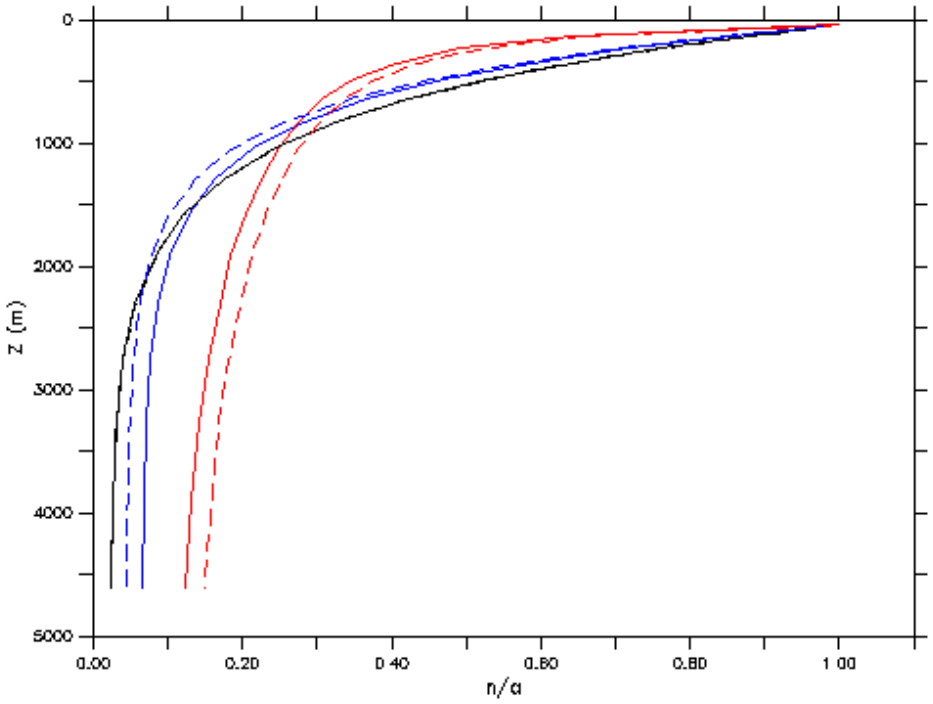
µmol kg^{-1}

Atlantic



µmol kg^{-1}

Changes in POC profiles



export−normalized particulate flux − POC (n/a)

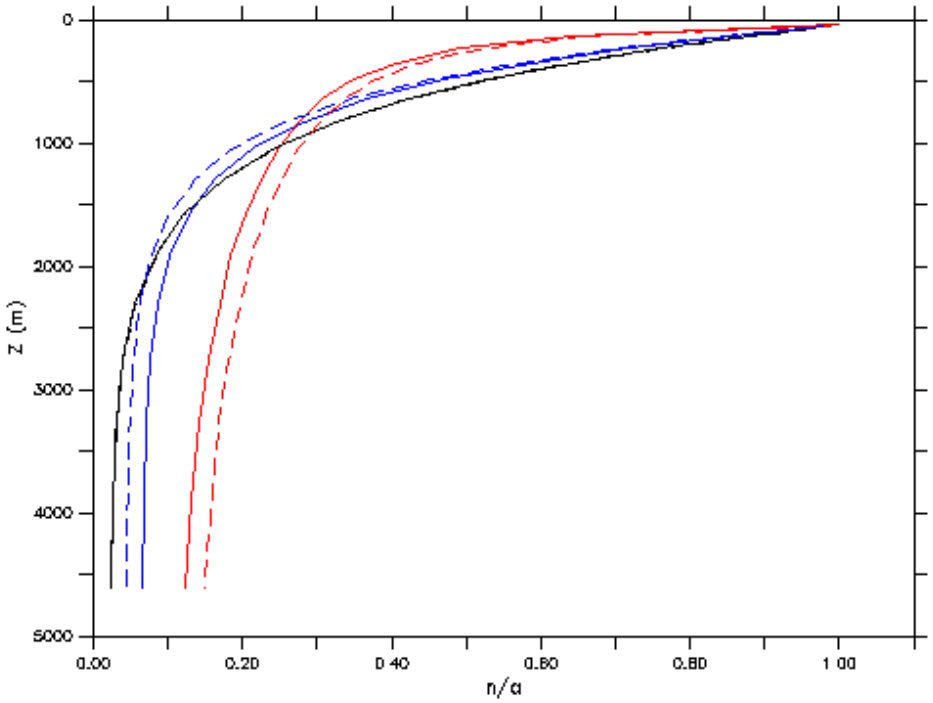
Standard ——— 2010

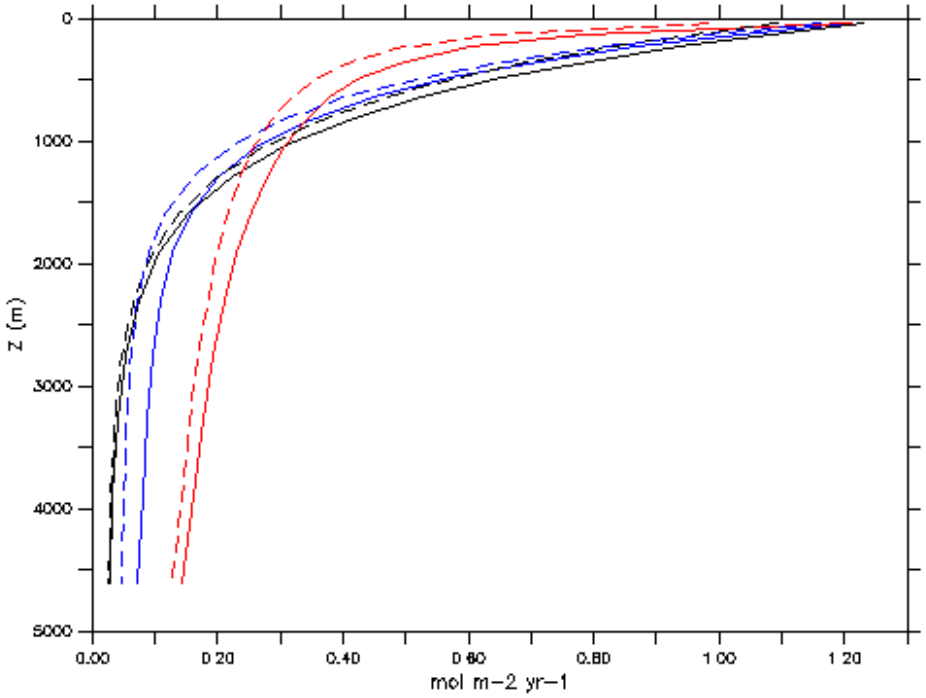
Ballasting

Henson (SST) - - - 2500

Changes in POC profiles

Decreased export





Standard ——— 2010

Ballasting

Henson (SST) - - - 2500