New Approach to Modeling Neodymium: Testing the Bottom-up hypothesis

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Background → History of Nd Modeling → Our New Approach Set up → Results

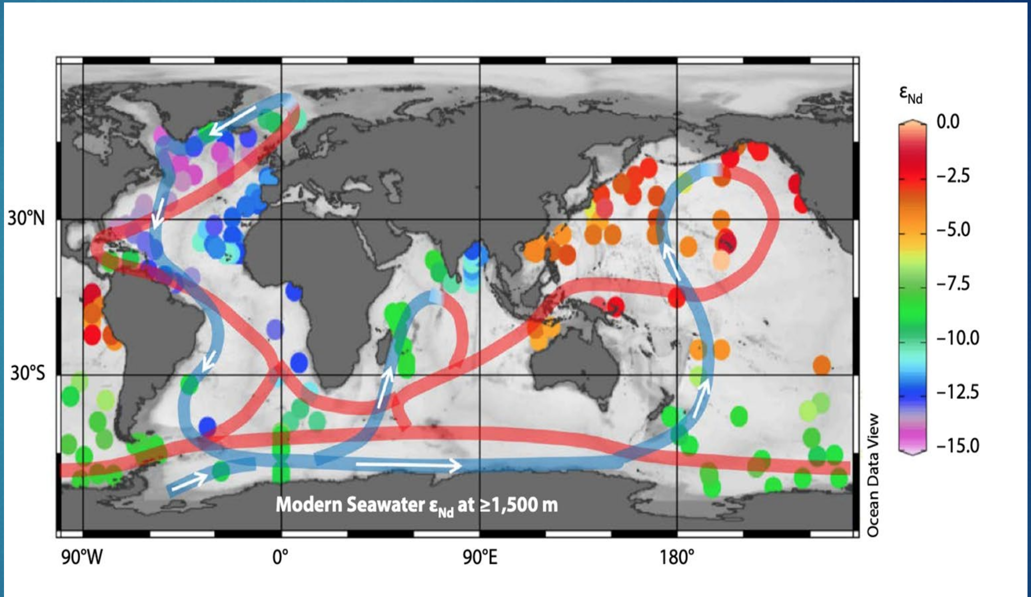
Background information

General information:

- Rare Earth Element
- Isotopes formed from alpha decay of Samarium (Sm)

Why do we use ƐNd as a tracer?

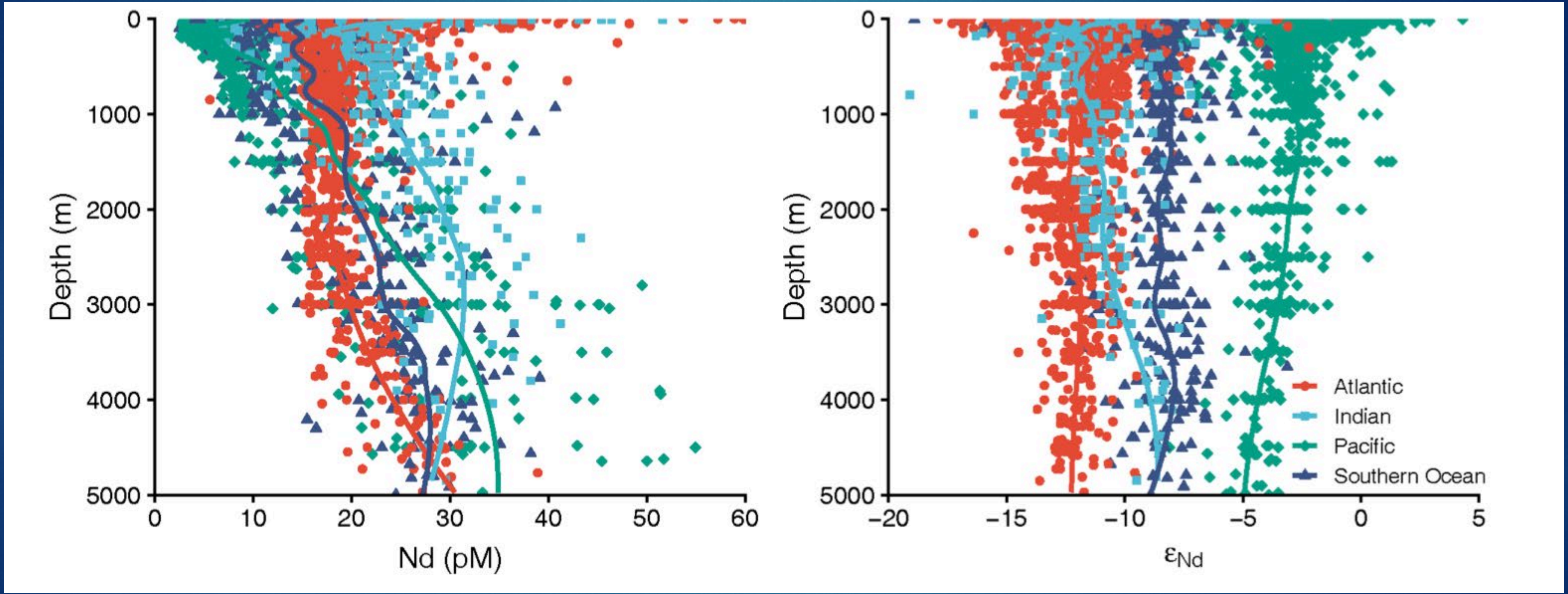
- Negligible biological fractionation
- Air-sea exchange
- Quasi-conservative



Tachikawa et al., 2020

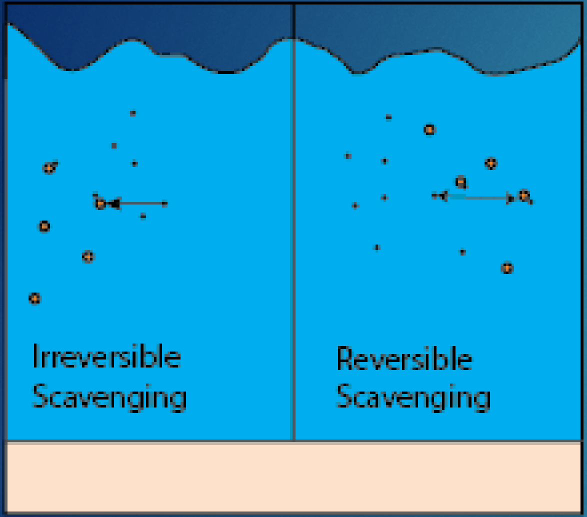
Radiogenic

Unradiogenic

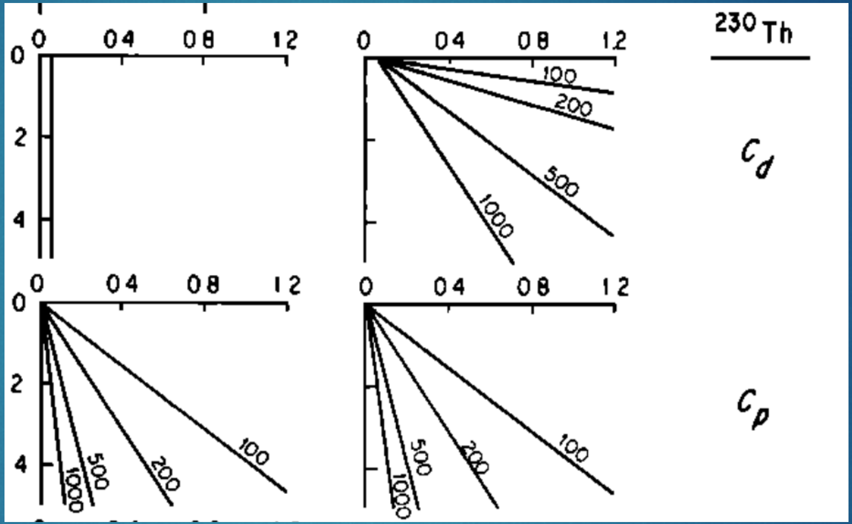

Depth (m)
0
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
Nd (pM)
Depth (m)
0
1000
2000
3000
4000
5000
−20
−15
−10
−5
0
5
ε_{Nd}
Atlantic
Indian
Pacific
Southern Ocean

Du, 2019

History of Neodymium modeling



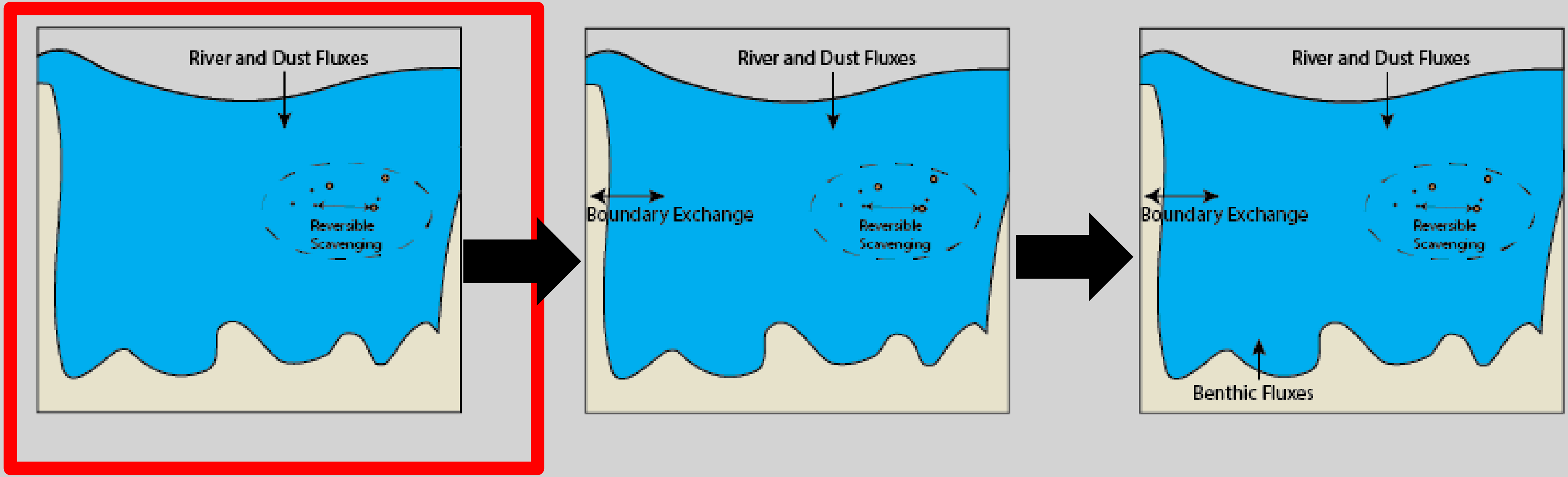
Irreversible Reversible



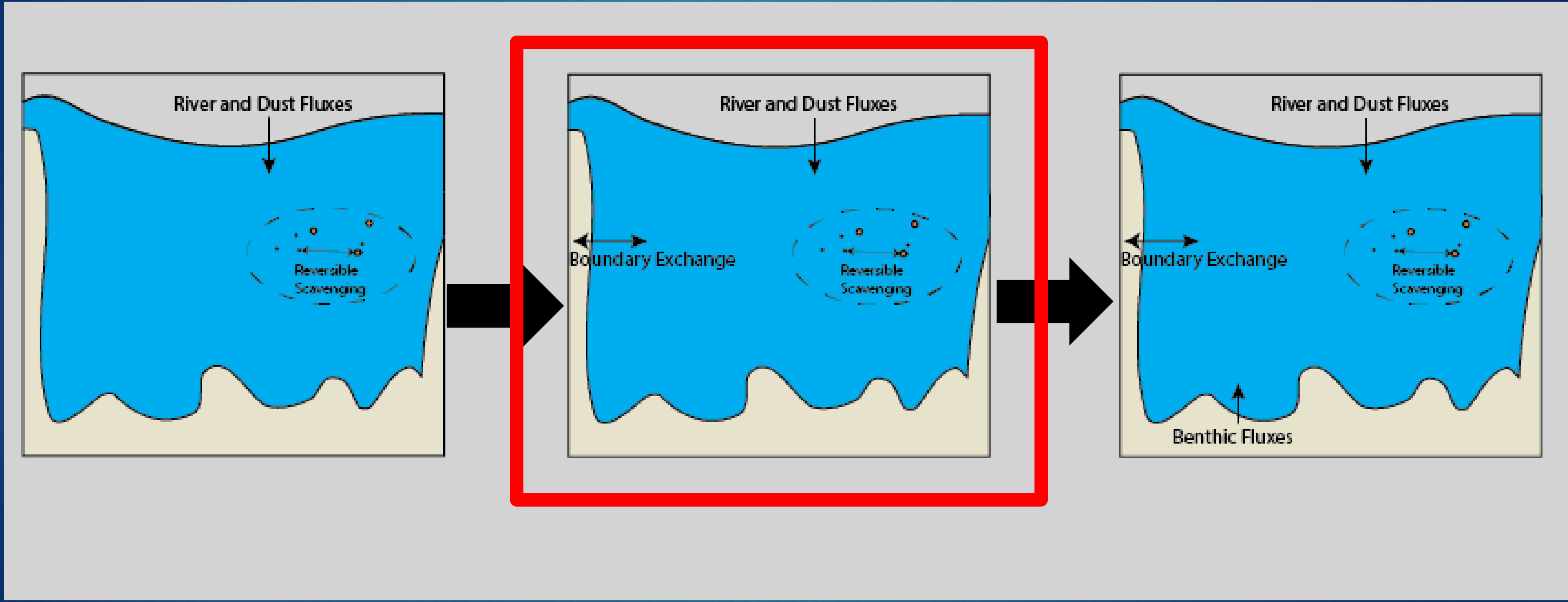
Bacon and Anderson, 1982

- Constant production in the water column
- No vertical diffusivity
- Constant sinking speed
- High Cp/Cd ratio

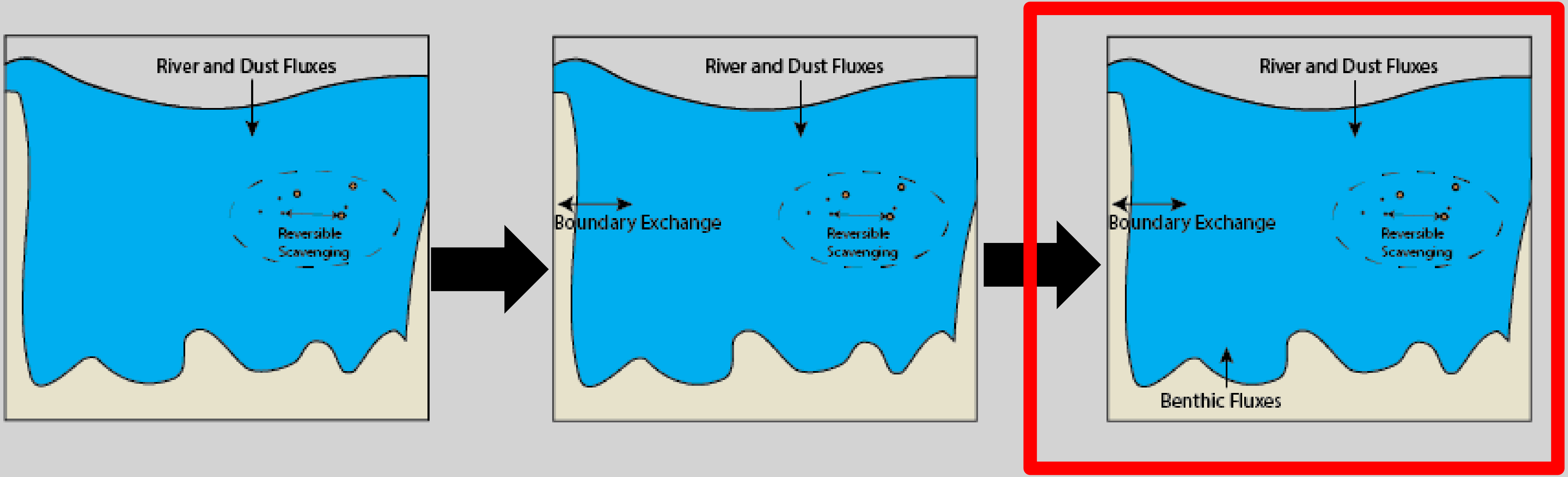
History of Neodymium modeling



History of Neodymium modeling



History of Neodymium modeling

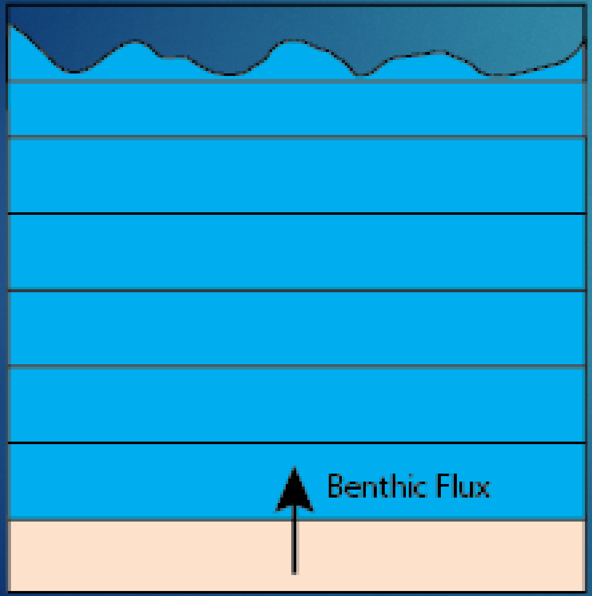


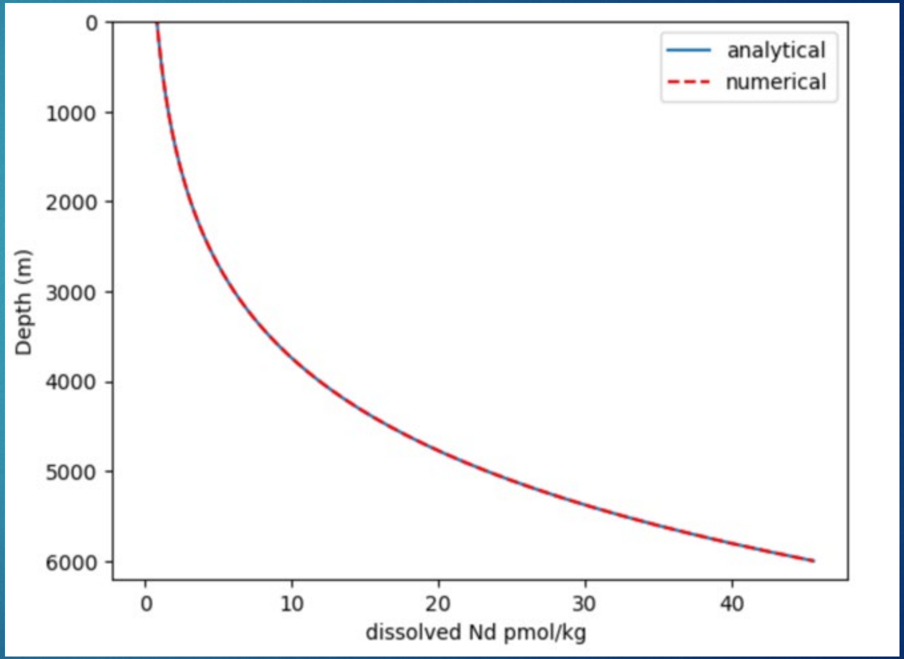
New Approach: Testing the bottom-up hypothesis

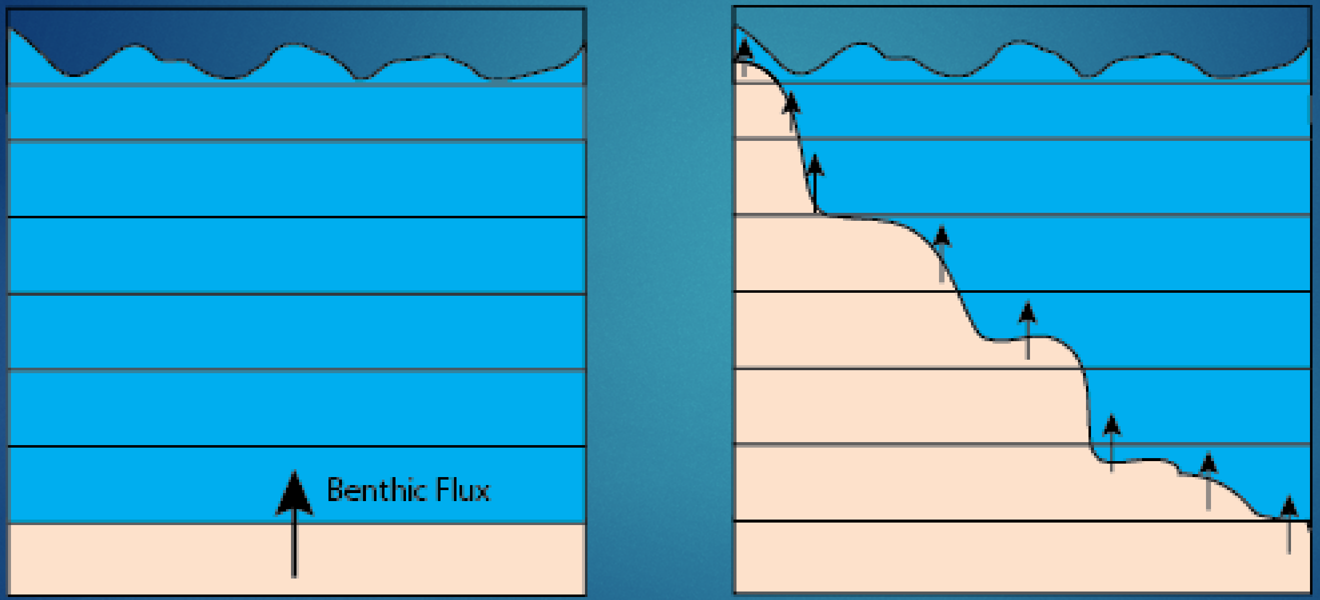
Absorption

$$\frac{\partial Cd}{\partial t} = k_v \frac{\partial^2 C_d}{\partial z^2} - k_p C_d + F_b$$

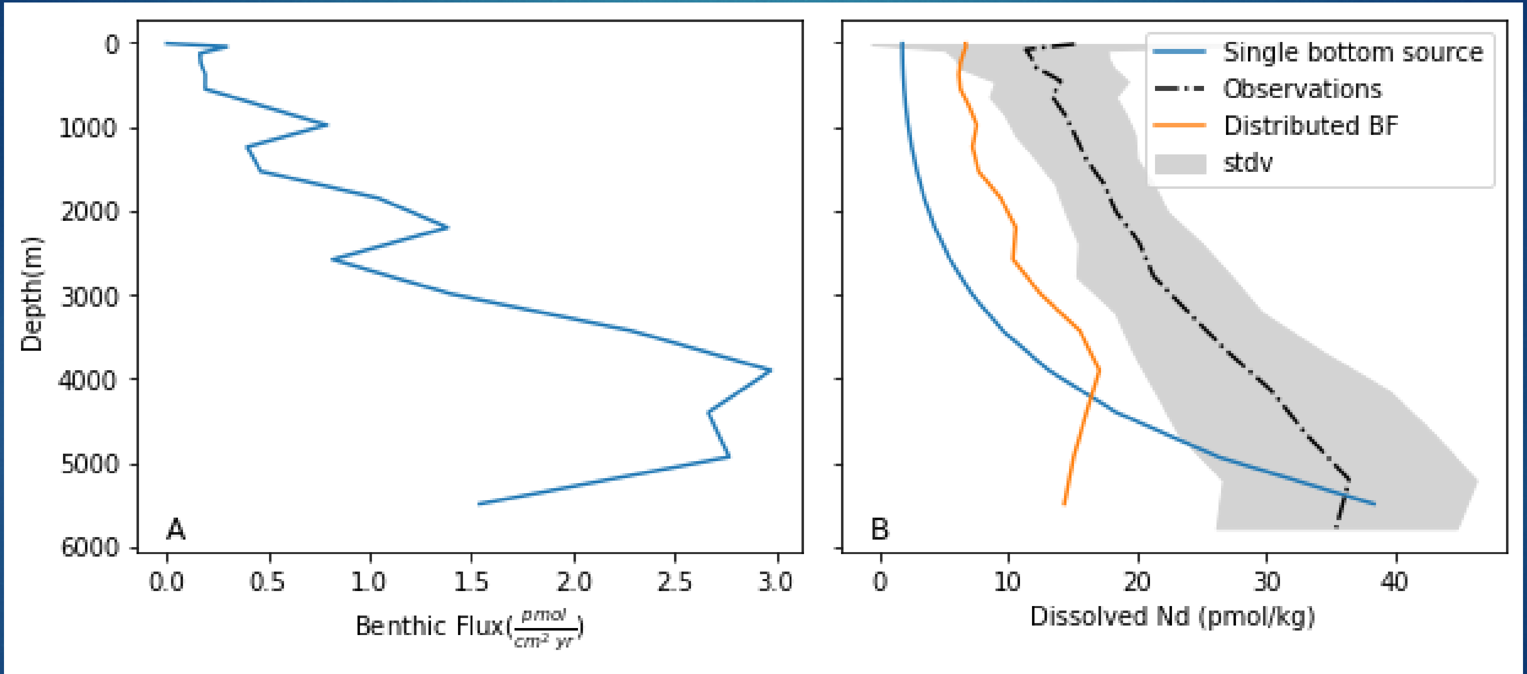
Diffusion Benthic Flux

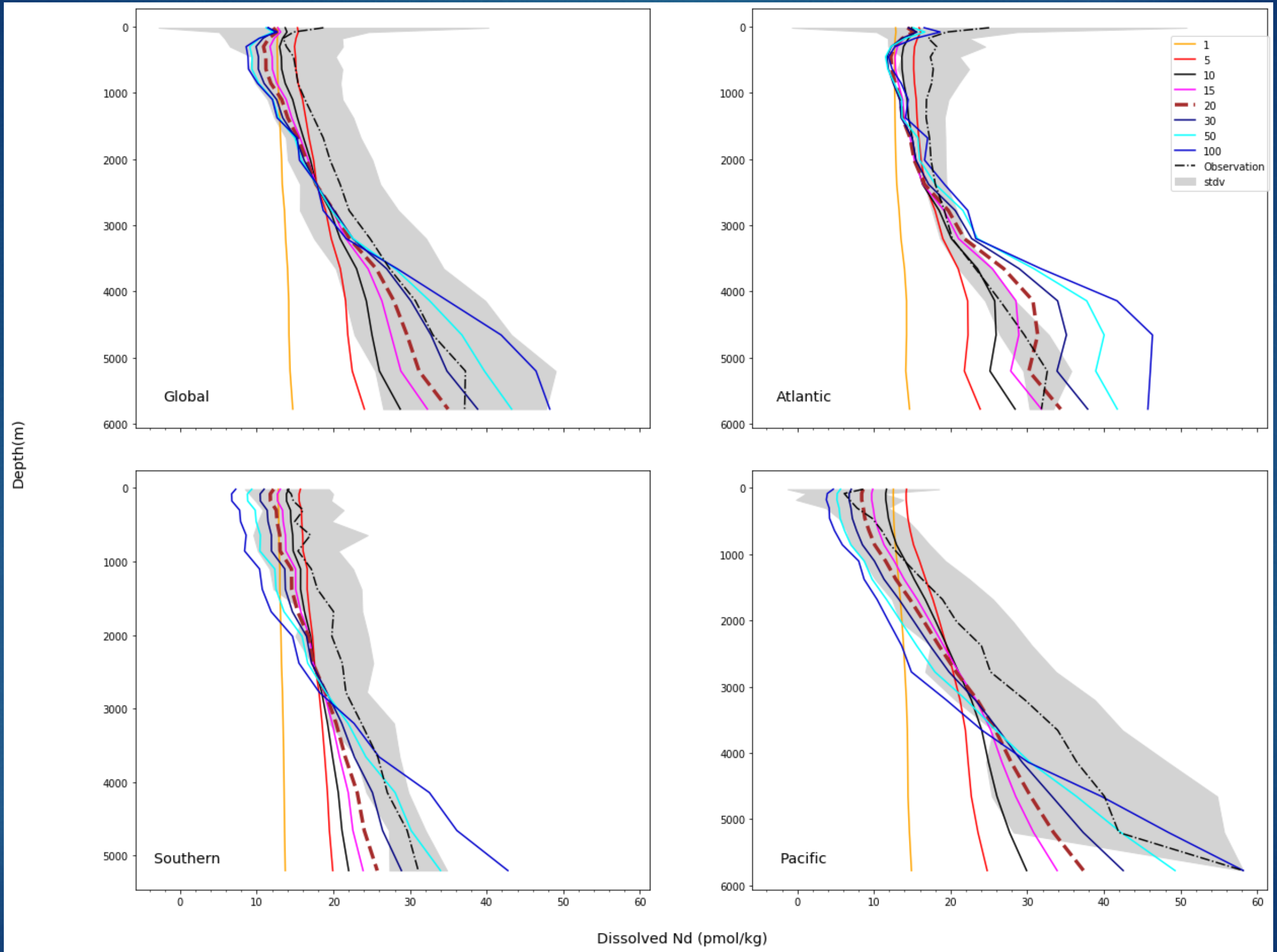


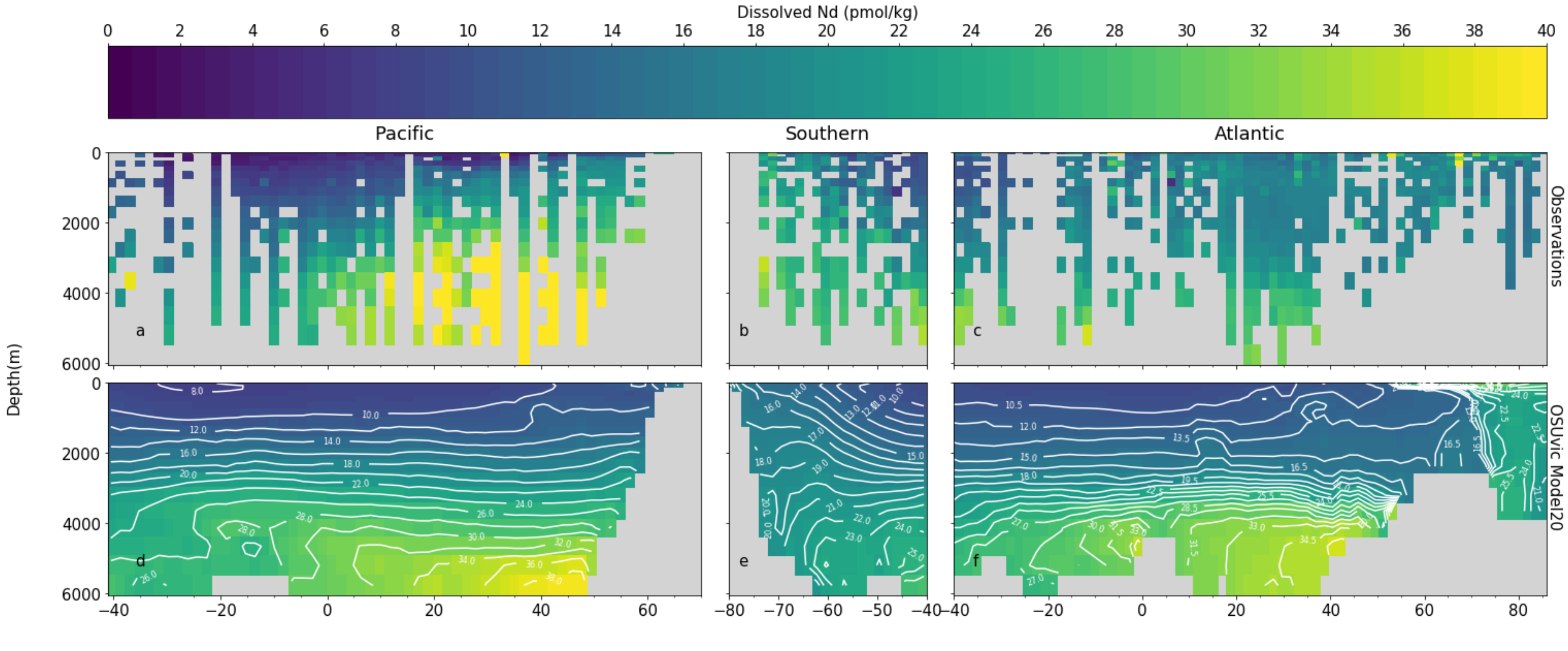



Benthic Flux

$$\frac{\partial Cd}{\partial t} = k_v \frac{\partial^2 C_d}{\partial z^2} - k_p C_d + \boxed{F_b}$$

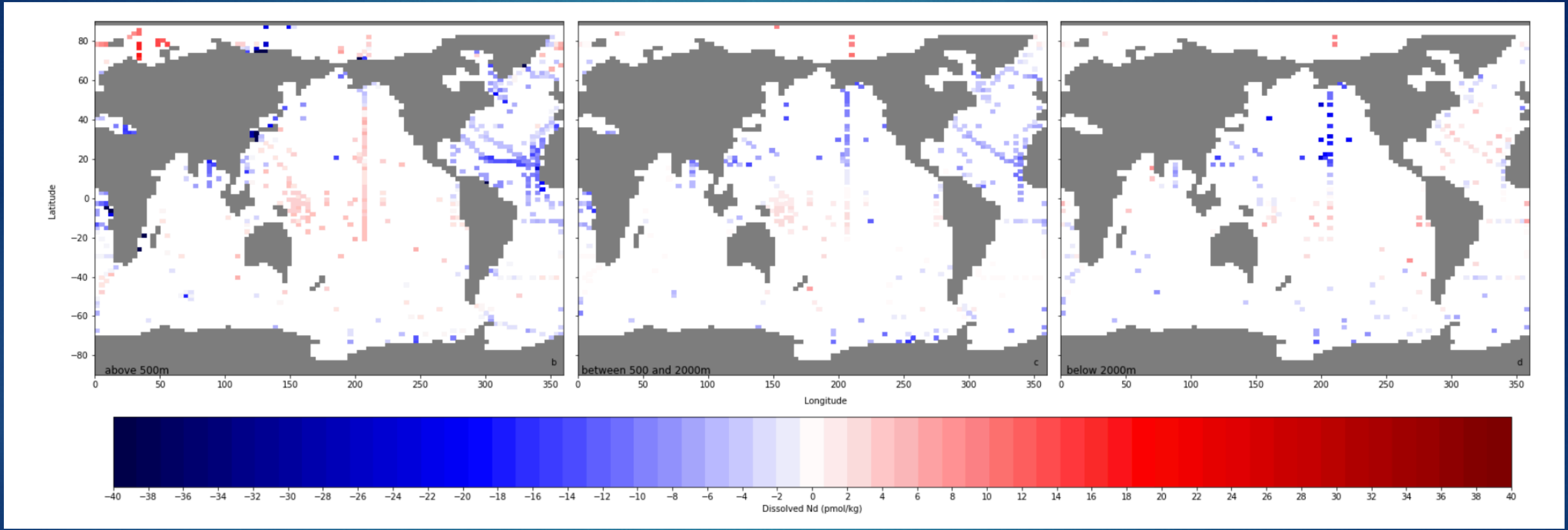



Global
Atlantic
Southern
Pacific
1
5
10
15
20
30
50
100
Observation
stdv
Depth(m)
Dissolved Nd (pmol/kg)

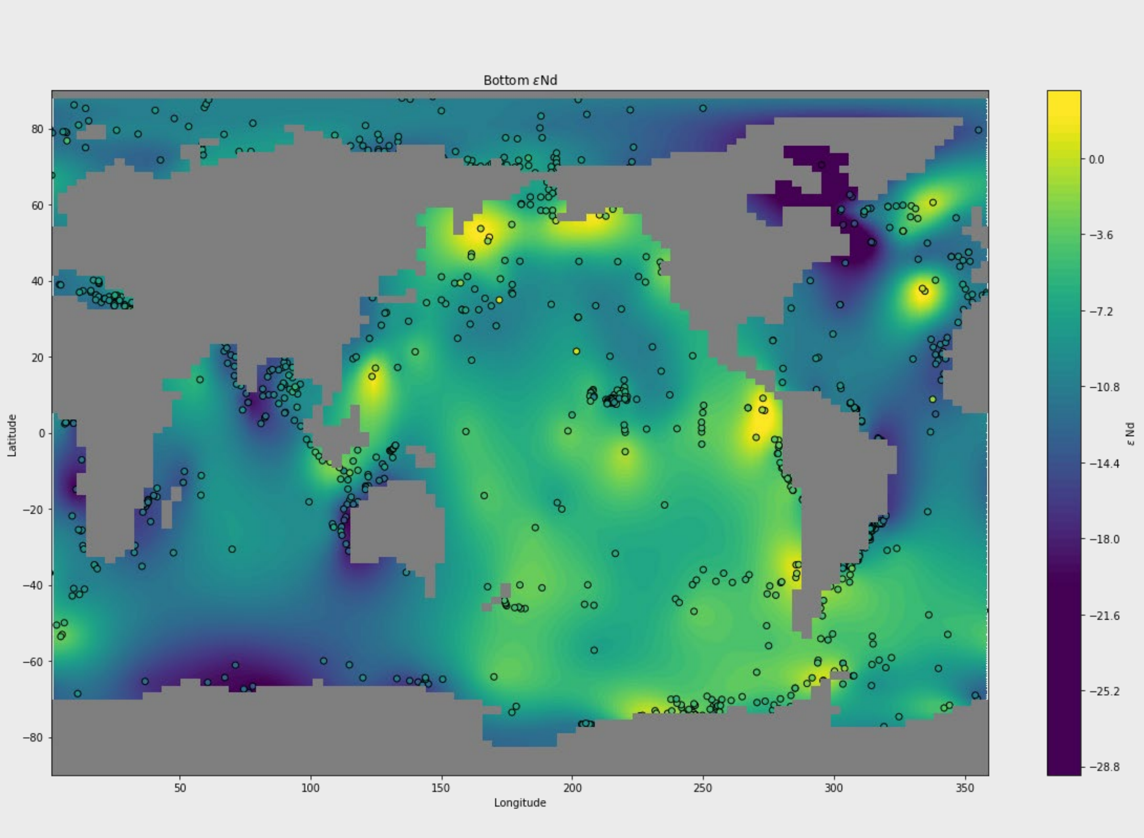

Dissolved Nd (pmol/kg)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Pacific
Southern
Atlantic
Observations
OSUvic Model20
Depth(m)
0
2000
4000
6000
a
b
c
d
e
f
−40 −20 0 20 40 60
−80 −70 −60 −50 −40
−40 −20 0 20 40 60 80
Latitude degrees N

RMSE:10.4

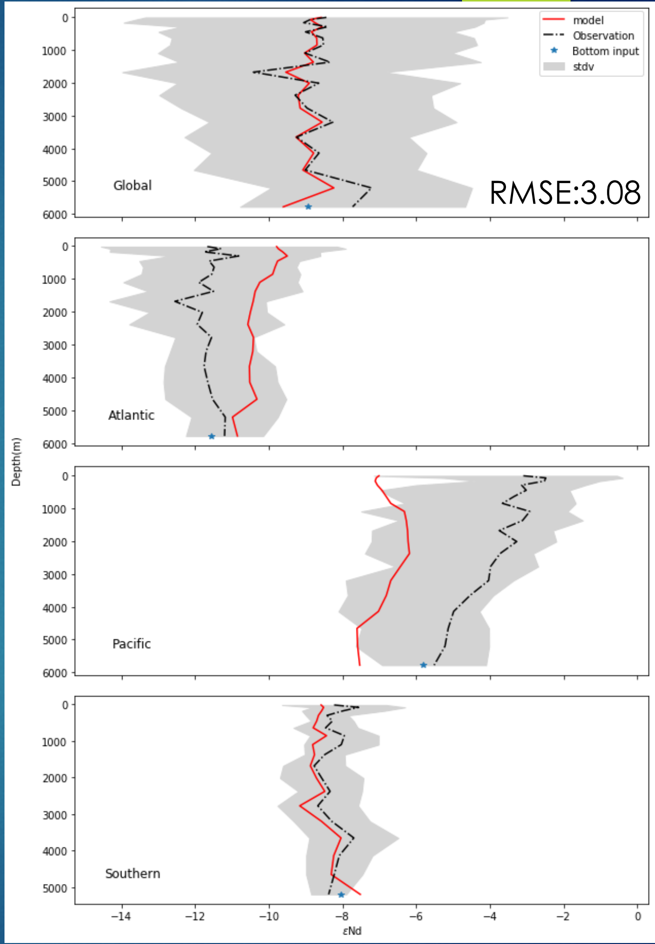
Above 500m | 500m -2000m | Below 2000m



Future work



Bottom εNd
Latitude
Longitude
ε Nd



model
Observation
Bottom input
stdv
Global
RMSE:3.08
Atlantic
Pacific
Southern
Depth(m)
εNd

Some Key Points

- A constant benthic flux, vertical diffusion, and irreversible scavenging result in dissolved Neodymium concentrations close to observations

- The bathymetry of the ocean, diffusion, and lateral transport lead to linearly increasing Neodymium concentrations with depth in the palagic ocean without the need for reversible scavenging

- Reversible scavenging does not play a major role in Neodymium distributions when using a bottom-up approach.

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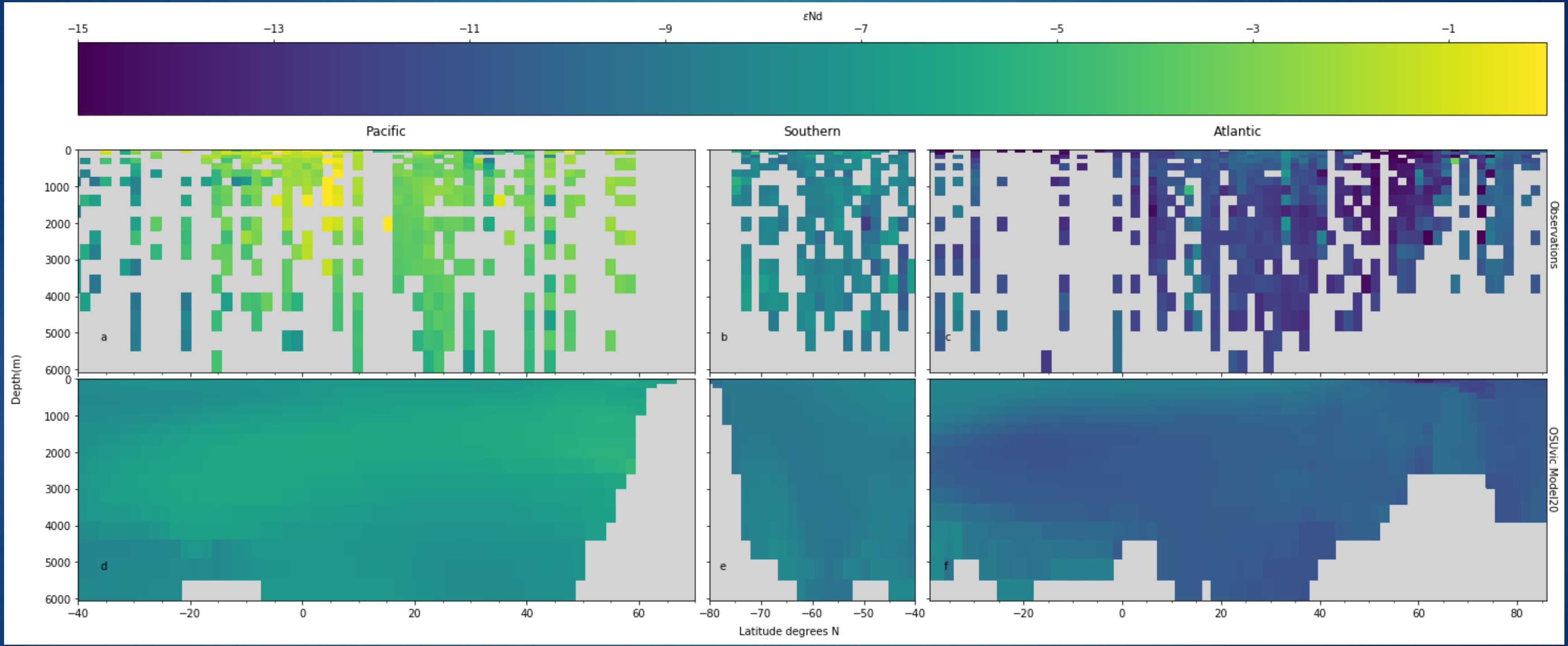
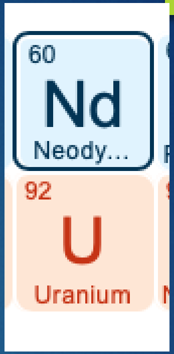
Extra slides for Possible Questions



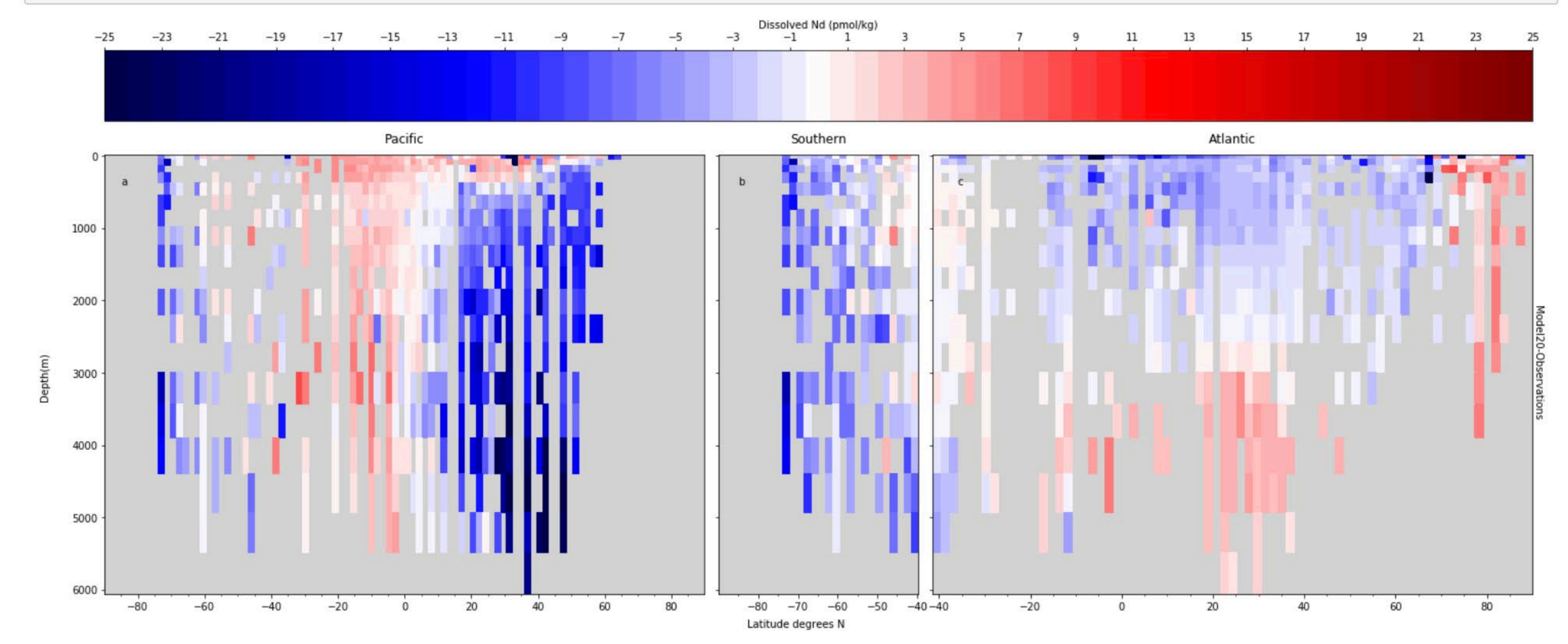
Background

- Rare Earth Element
- Isotopes formed from alpha decay of Samarium (Sm)
- CHUR: present-day Chondritic Uniform Reservoir 0.512638

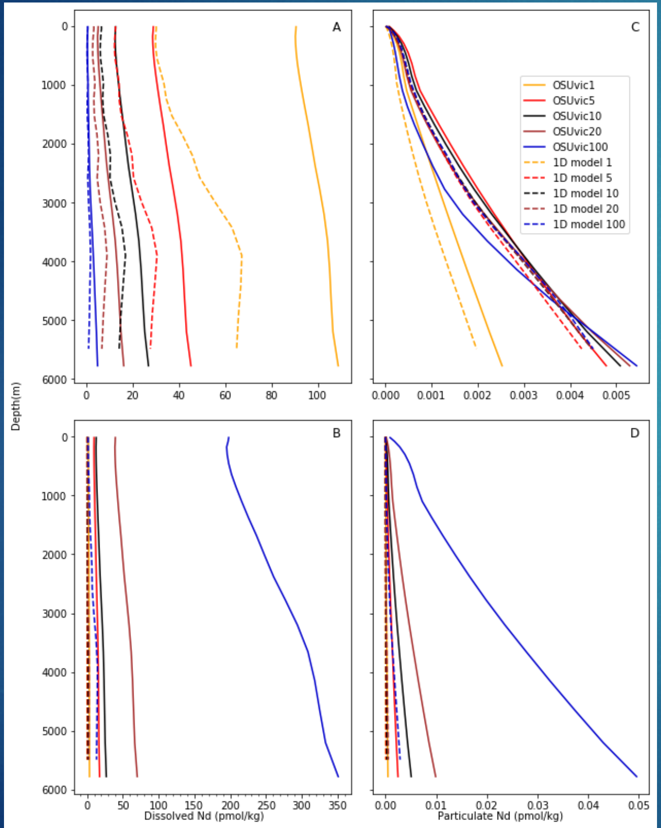


$$\epsilon_{Nd} = \left(\frac{(^{143}Nd/^{144}Nd)_{sample}}{(^{143}Nd/^{144}Nd)_{CHUR}} - 1 \right) \times 10^4$$

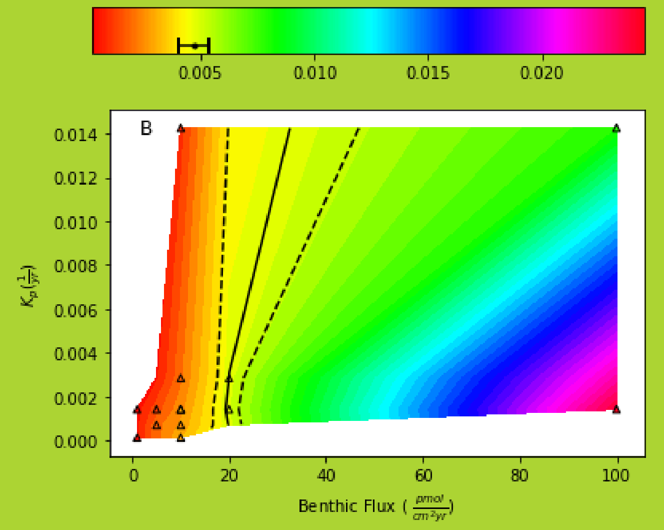
Jacobsen and Wasserburg, 1980

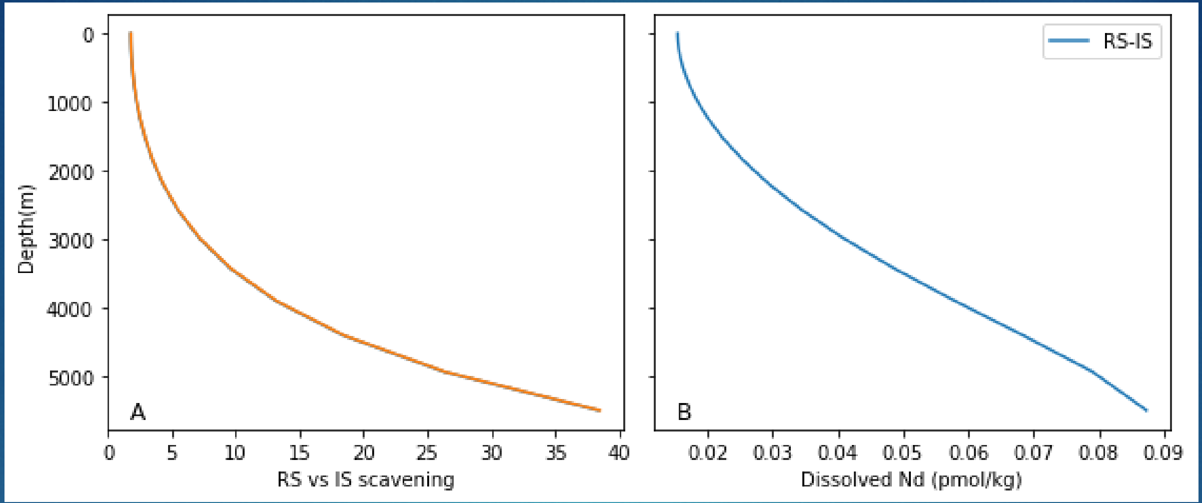

Dissolved Nd (pmol/kg)
−25 −23 −21 −19 −17 −15 −13 −11 −9 −7 −5 −3 −1 1 3 5 7 9 11 13 15 17 19 21 23 25
Pacific
Southern
Atlantic
a
b
c
Depth(m)
0
1000
2000
3000
4000
5000
6000
−80 −60 −40 −20 0 20 40 60 80
−80 −70 −60 −50 −40
−40 −20 0 20 40 60 80
Latitude degrees N
Model20-Observations

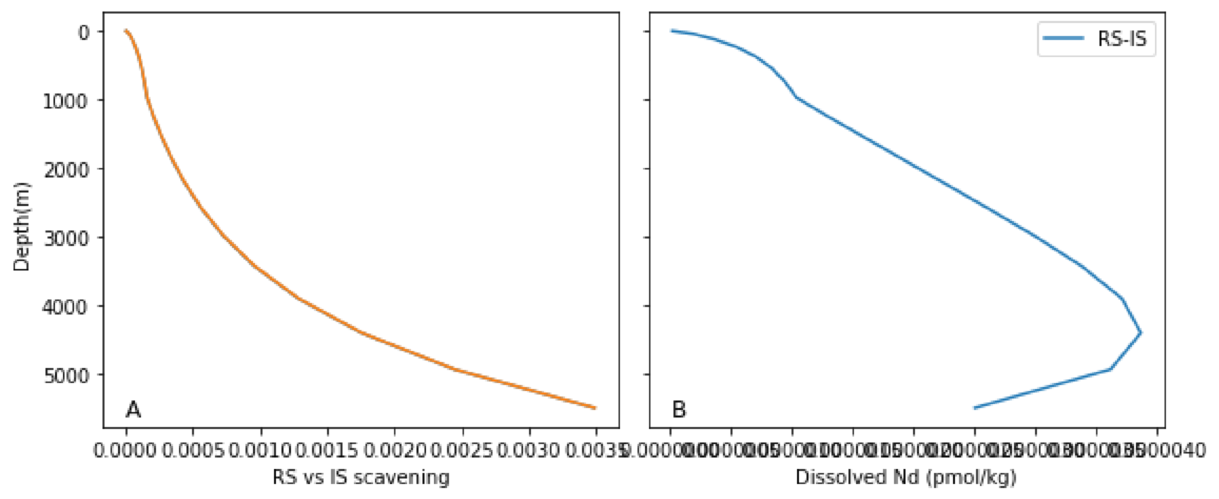
- Top: variable K_p
- Bottom: variable Benthic flux



BF(pmol cm^{-2} yr^{-1})	K_p (1/yr)
1	0.14×10^{-3}
5	0.71×10^{-3}
10	1.4×10^{-3}
20	2.9×10^{-3}
100	14×10^{-3}




Depth(m)
0
1000
2000
3000
4000
5000
A
0
5
10
15
20
25
30
35
40
RS vs IS scavening
RS-IS
B
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
Dissolved Nd (pmol/kg)


Depth(m)
0
1000
2000
3000
4000
5000
A
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
0.0030
0.0035
RS vs IS scavening
RS-IS
B
Dissolved Nd (pmol/kg)

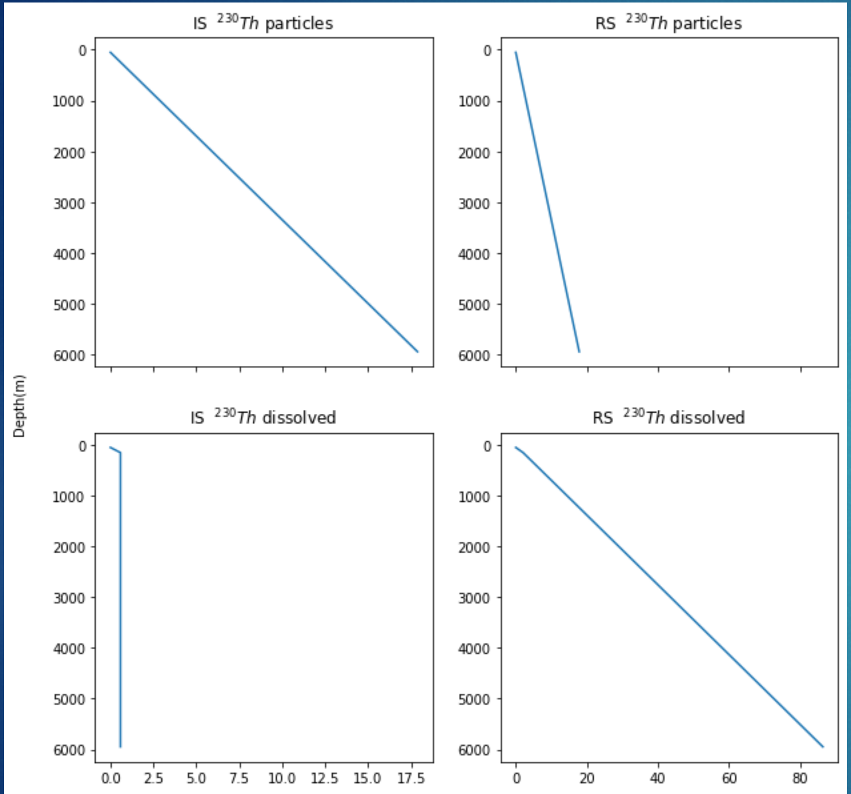


Figure S.1. The left side shows irreversible scavenging (IS) for both dissolved (bottom) and particulate (top) phase ^{230}Th, and the right shows the reversible scavenging (RS) results using the values shown in Table S.1.

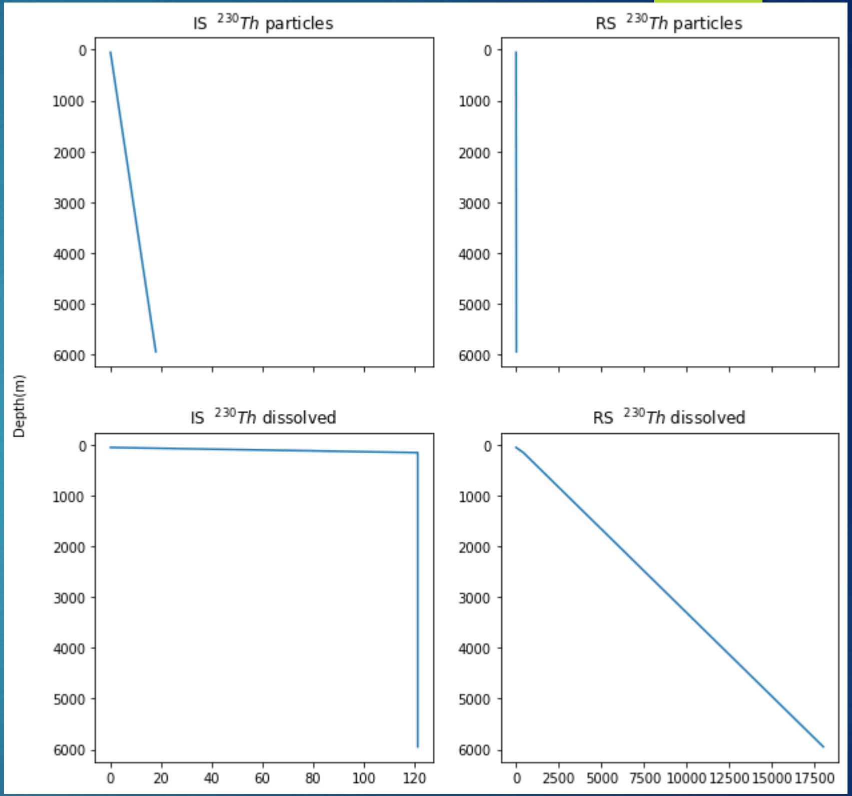


Figure S.2 Modified scavenging based on C_p/C_d ratio of 0.001. The left side shows IS results, and the right shows RS results. The particulate (top) and dissolved (bottom) concentrations.

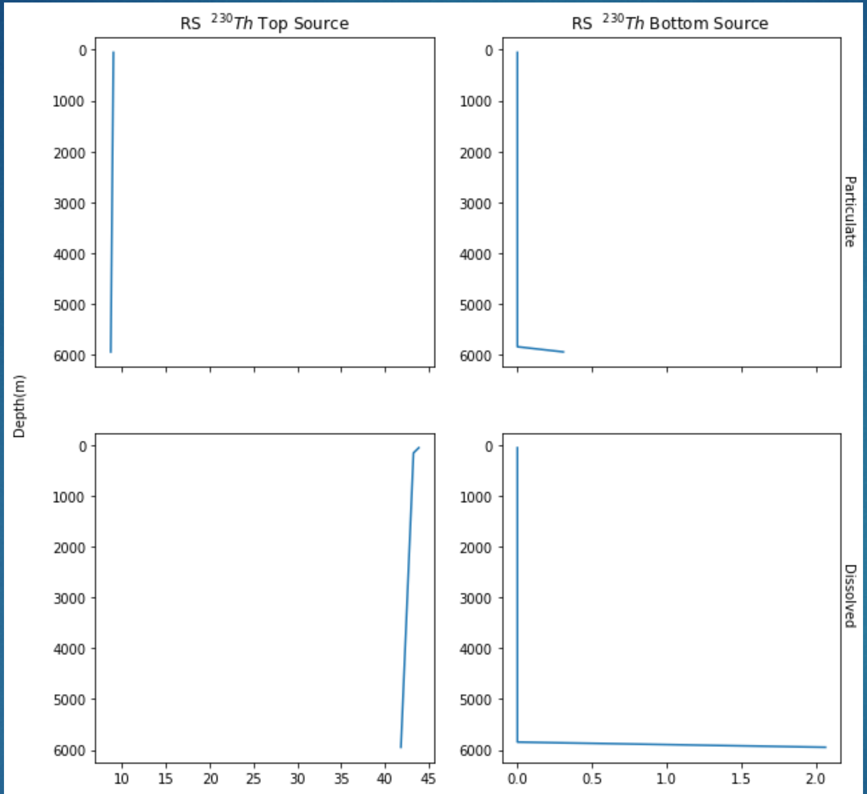
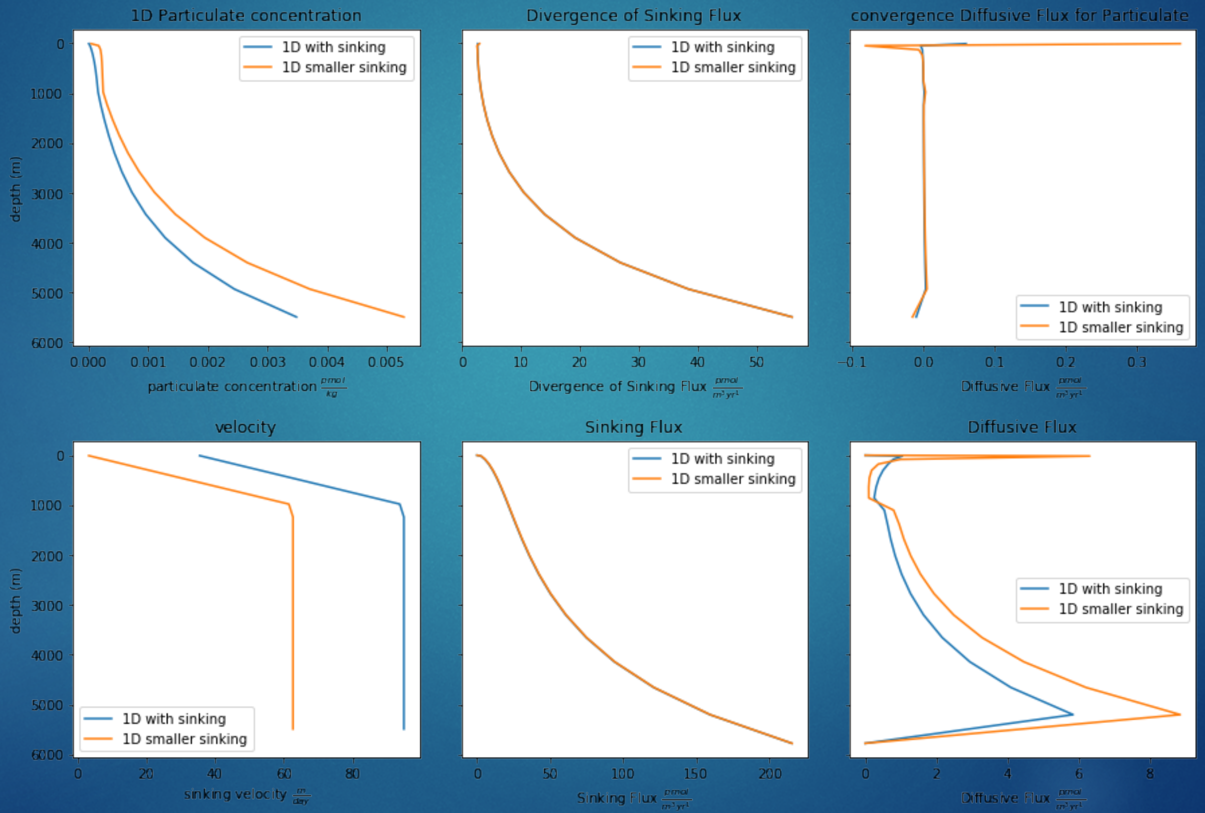


Figure S.3. RS results for a top-only source (left) and a bottom-only source(right). The particle (top) and dissolved (bottom) concentrations.



1D Particulate concentration
1D with sinking
1D smaller sinking
depth (m)
particulate concentration $\frac{pmol}{kg}$
Divergence of Sinking Flux
Divergence of Sinking Flux $\frac{pmol}{m^3 yr^1}$
convergence Diffusive Flux for Particulate
Diffusive Flux $\frac{pmol}{m^3 yr^1}$
velocity
sinking velocity $\frac{m}{day}$
Sinking Flux
Sinking Flux $\frac{pmol}{m^2 yr^1}$
Diffusive Flux
Diffusive Flux $\frac{pmol}{m^2 yr^1}$

Fun Math for Fun Math people

Thorium IS equations:

$$\frac{\partial C_d}{\partial t} = Pd - kp\ C_d$$

$$C_{d_{[t+1]}} = \left(Pd - k_p C_{d_{[t]}}\right) * \Delta t + C_{d_{[t]}}$$

$$\frac{\partial C_p}{\partial t} = k_p C_d - S\frac{\partial C_p}{\partial z}$$

$$C_{p_{[t+1]}} = \left(k_p C_{d_{[t]}} - S\frac{\Delta C_p}{\Delta z}\right) * \Delta t + C_{p_{[t]}}$$

Thorium RS equations:

$$\frac{\partial C_d}{\partial t} = Pd - \left(\lambda + k_p\right)C_d + k_{p-1}C_p$$

$$C_{d_{[t+1]}} = \left(Pd - \left(k_p\right)C_{d_{[t]}} + k_{p-1}C_{p_{[t]}}\right) * \partial t + C_{d_{[t]}}$$

$$\frac{\partial C_p}{\partial t} = \left(k_p\right)C_d - (\lambda + k_{p-1})C_p - S\frac{\partial C_p}{\partial z}$$

$$C_{p_{[t+1]}} = \left(\left(k_p\right)C_{d_{[t]}} - S\frac{\partial C_p}{\partial z} - k_{p-1}C_{p_{[t]}}\right) * \partial t + C_{p_{[t]}}$$

Pd	**0.303 mol/yr**
λ	9.2 x 10^{-6} yr^{-1}
S	100 m/yr
k_p	0.52 yr^{-1}
k_{p-1}	2.5 yr^{-1}

Fun Math for Fun Math people

- Analytical Solution:

$C_d = C_{d0}e^{z/\zeta} = C_{dH}e^{(-(H-z)/\zeta)}$

where $\zeta = \sqrt{\frac{k_v}{k_p}}$ is the e-folding depth, H is the depth at the sea floor, $C_{d0} = C_{dH}e^{-H/\zeta}$

- Numerical Solution:

$C_{d[n+1]} = \left(\frac{\Delta F_d}{\Delta z} - k_{p_{C_d}} + \frac{F_b}{\Delta z}\right)\Delta t + Cd_{[n]}$

$C_{p[n+1]} = \left(\frac{\Delta F_d}{\Delta z} + k_p * C_d - F_s\right)\Delta t + C_{p[n]}$

Where $F_d = k_v \frac{\Delta C_p}{\Delta z}$ is the diffusive flux and $F_s = \frac{\Delta(S*C_p)}{\Delta z}$ is the sinking flux

adsorption coefficient as the inverse of residence time $k_p = 1/\tau_R$

$\tau_R = (\underline{C_d}\rho)/(F_b/H)$, where $\underline{C_d}$ is the global mean dissolved concentration, $\rho = 1020\ kg/m^3$ is the average sea water density, F_b is the benthic flux, and H = 4 km is the depth of the water column. $\underline{C_d}$ = 17.4 pmol/kg

- $A_r=A_b/A_T$
- $F_{b\_dist}=F_b*A_r$

History of Neodymium modeling

- Bacon and Anderson 1982
- Bertram and Elderfield 1993
- Henderson et al. 1999
- Siddal et al. 2005
- Arsouze et al. 2007
- Siddall et al. 2008
- Arsouze et al. 2009
- Rempfer et al. 2011
- Gu et al. 2019
- Pasquier et al. 2021
- Oka et al. 2021
- Robinson et al. 2022
- Poppelmeier et al. 2022

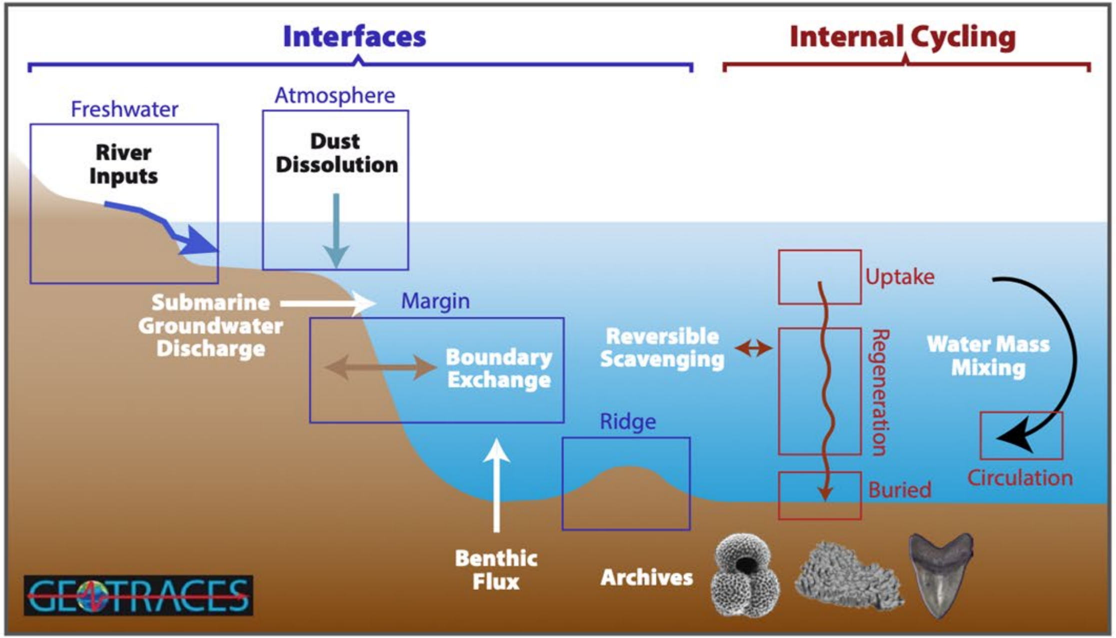
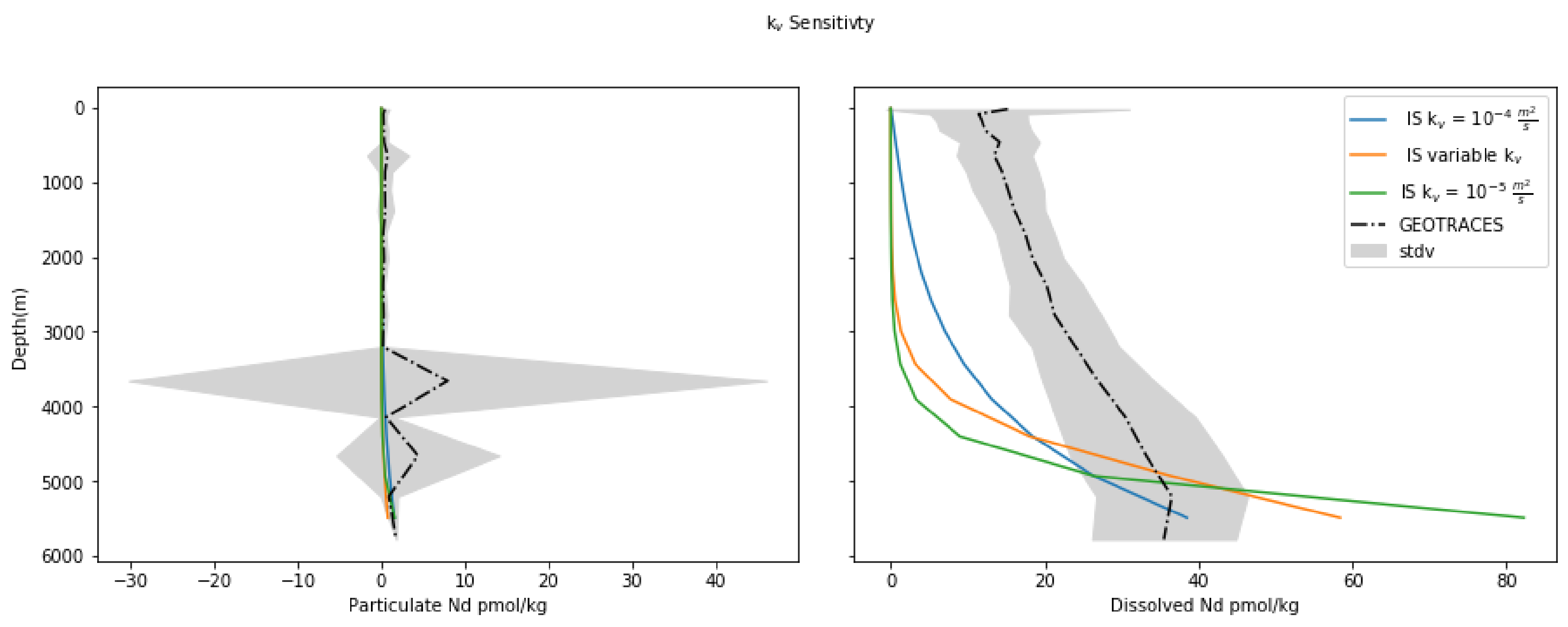


FIGURE 2. Neodymium sources and processes affecting oceanic Nd concentration and isotopic composition as well as possible marine sedimentary records of Nd isotopic composition. Figure based on data from GEOTRACES (http://www.geotraces.org/) modified to summarize the oceanic Nd cycle.



k_v Sensitivty
Depth(m)
0
1000
2000
3000
4000
5000
6000
−30
−20
−10
0
10
20
30
40
Particulate Nd pmol/kg
0
20
40
60
80
Dissolved Nd pmol/kg
IS k_v = 10^−4 m²/s
IS variable k_v
IS k_v = 10^−5 m²/s
GEOTRACES
stdv

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Tachikawa, K. "Neodymium Budget in the Modern Ocean and Paleo-Oceanographic Implications." *Journal of Geophysical Research* 108, no. C8 (2003): 3254. https://doi.org/10.1029/1999JC000285.