Neodymium isotopes in the ocean model of the CESM

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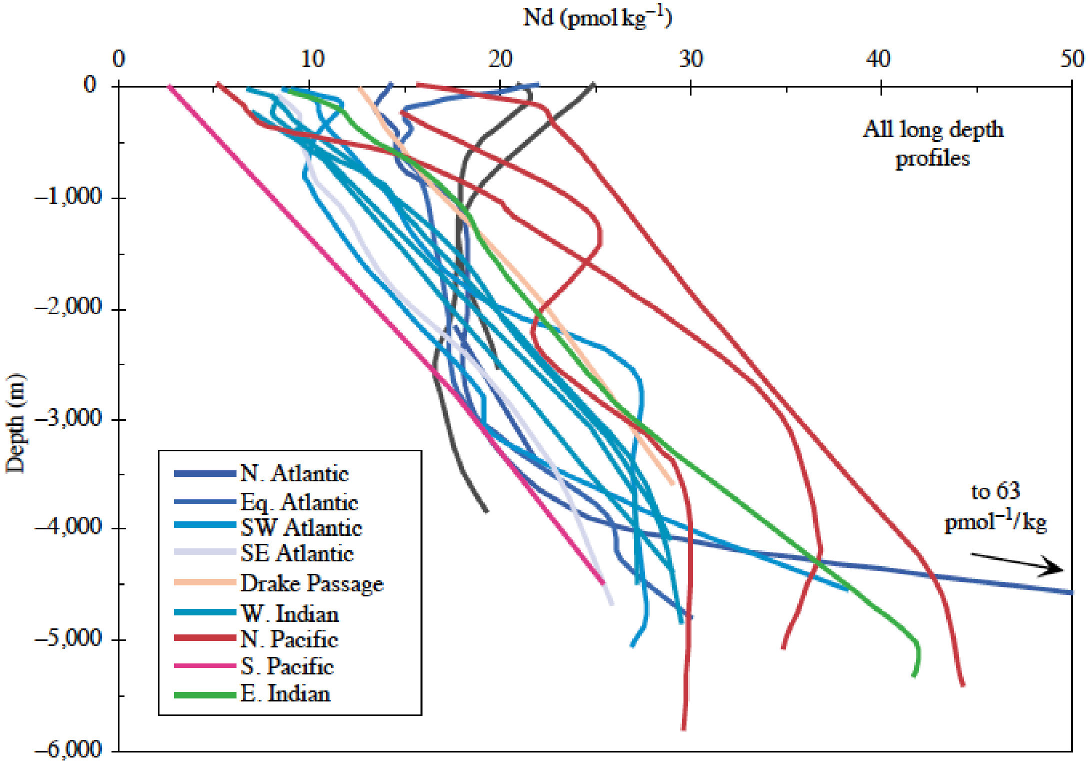
Outline

- Introduction of Nd isotopes
- Nd modeling scheme: sources and sinks
- Parameters tuning for Nd
- Results: Control and model sensitivity
- Summary

Introduction of Nd isotopes

- Nd isotopes: ^{144}Nd and radiogenic ^{143}Nd
- $^{147}Sm \rightarrow ^{143}Nd$, half life 106 billion years
- Nd concentration shows a nutrient-like behavior



Goldstein et al. 2003

Introduction of Nd isotopes: ε_{Nd}

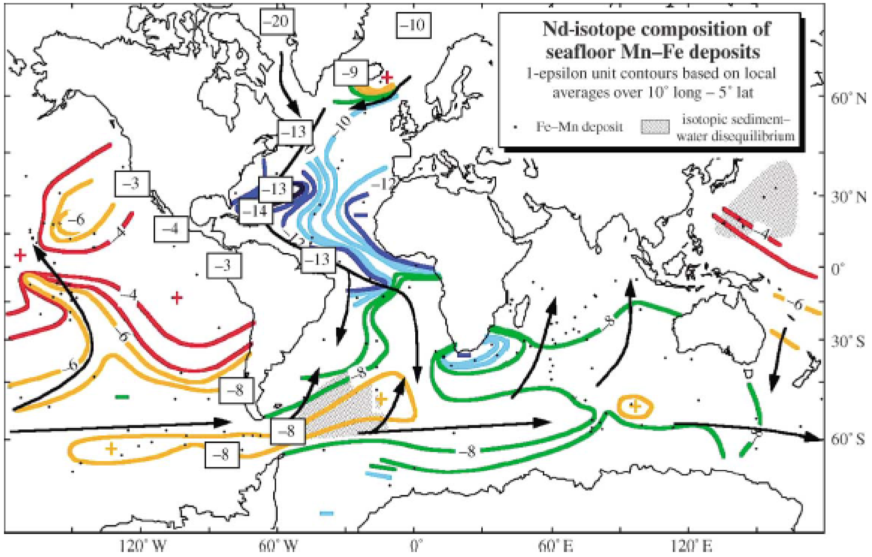
- Isotope ratio: $^{143}Nd/^{144}Nd$

$$\epsilon_{Nd} = [\frac{(\frac{^{143}Nd}{^{144}Nd})_{sample}}{(\frac{^{143}Nd}{^{144}Nd})_{bulkEarth}} - 1] \times 10^4$$

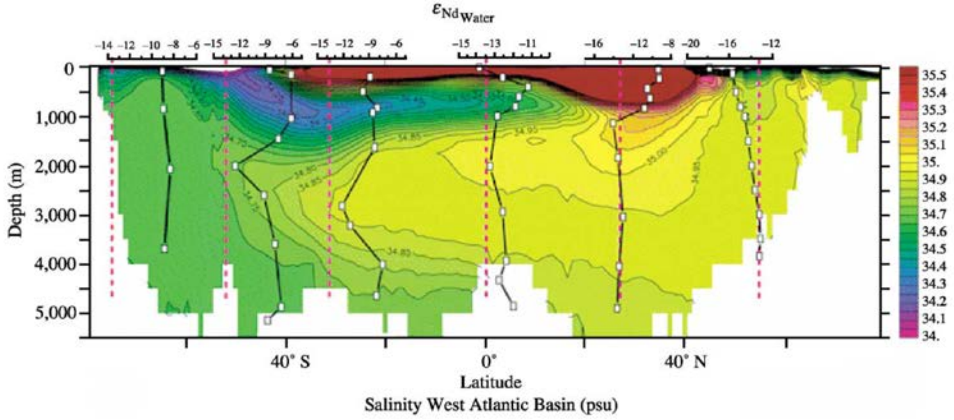
$(^{143}Nd/^{144}Nd)_{\text{bulk Earth}}$ is 0.512638

- Younger continent, larger (more radiogenic) ε_{Nd}

  Older continenet, smaller ε_{Nd}
- ε_{Nd} as water-mass mixing tracer:
  - AAIW:~-8 - -9
  - AABW: ~-9
  - NADW: ~-13 - -14
- Biological fractionation of Nd is negligible
- ε_{Nd} has been increasingly used in paleoceaography



Albare & Goldstein, 1992



von Blanckenburg, 1999

Nd modeling scheme

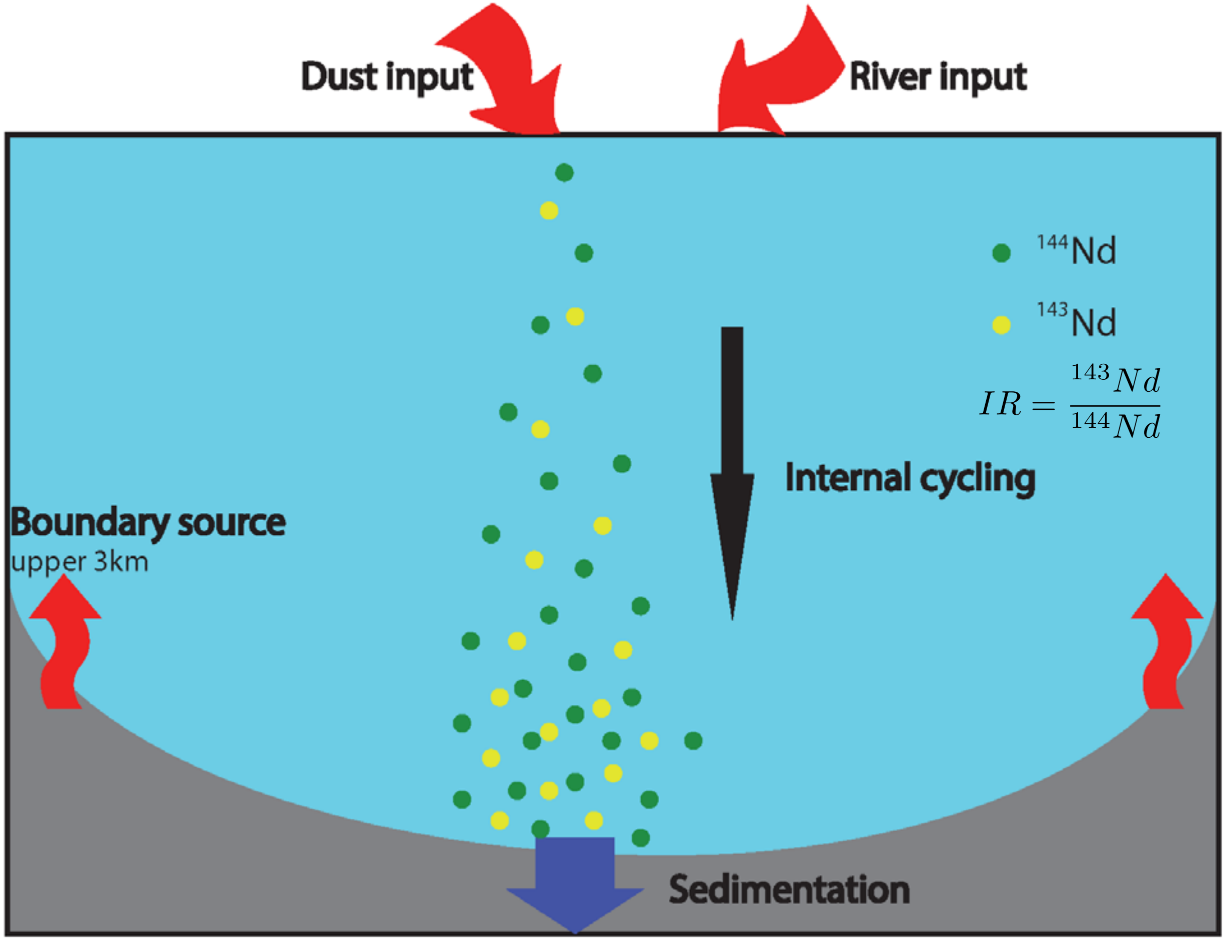
Implementation of Nd in CESM largely follows Rempfer et al. 2011 (Bern3D model):

^{143}Nd and ^{144}Nd are two separate tracers

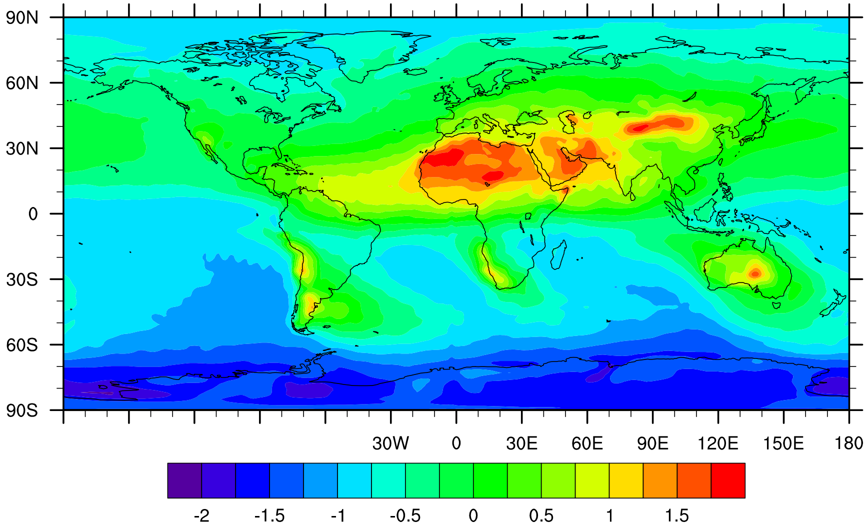
Sources: River, Dust & Boundary

Sink: Sedimentation

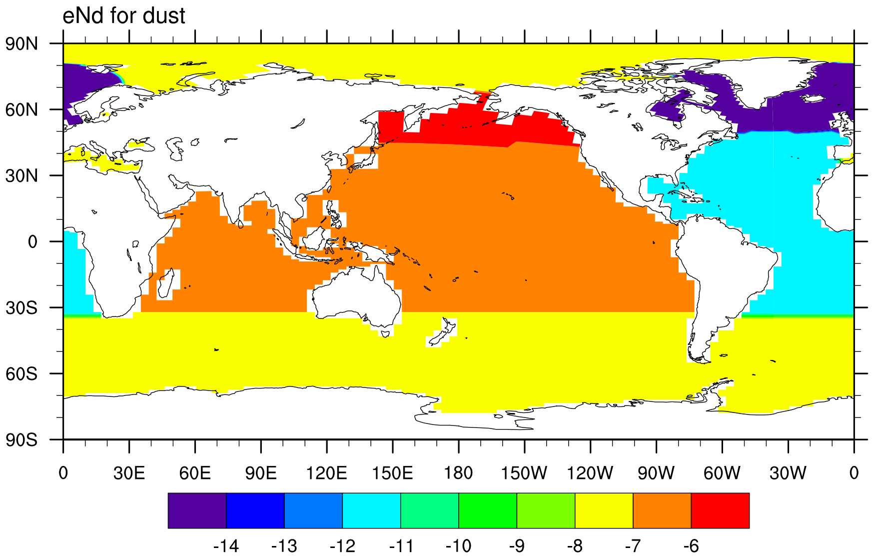
Internal Cycling: reversible scavenging



Nd modeling scheme: dust source



Mahowald et al., 2005



Tachikawa et al., 2003

$$S_{dust} = F_{dust} \times c_{dust} \times \beta_{dust} \times \frac{1}{\triangle z_1}$$

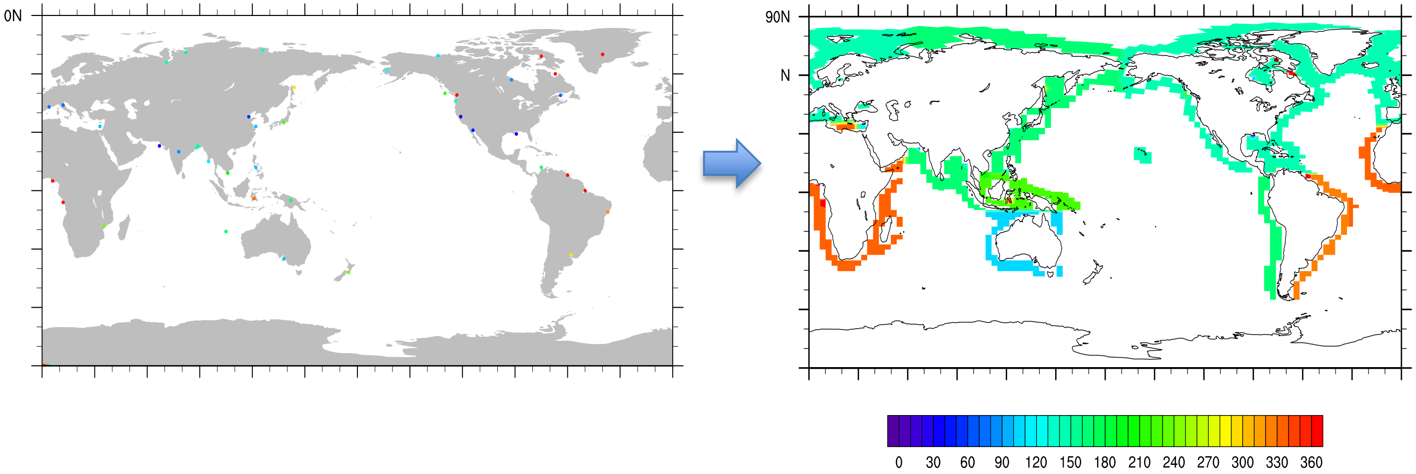
F_{dust}: surface dust flux

c_{dust}: global mean Nd concentration in dust, 20 µg/g, *Grousset et al., 1998*

β_{dust}: Nd release from dust, 20%, *Greaves et al., 1994*

Δz_1: thickness of first ocean layer

Nd modeling scheme: river source



Goldstein & Jacobsen, 1987

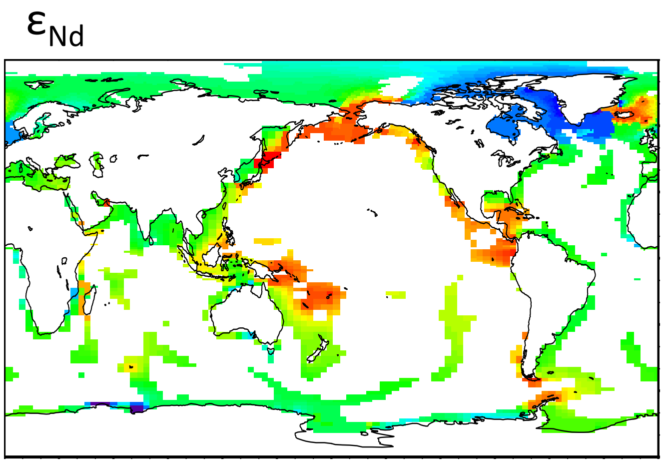
$$S_{river} = F_{river} \times c_{river} \times (1 - \gamma_{dust}) \times \frac{1}{\triangle z_1}$$

F_{river}: river runoff, from coupler

c_{river}: global mean Nd concentration in river

γ_{dust}: estuaries Nd removal,
0.7, *Elderfield et al., 1990*

Δz_1: thickness of first ocean layer



Jeandel et al., 2007

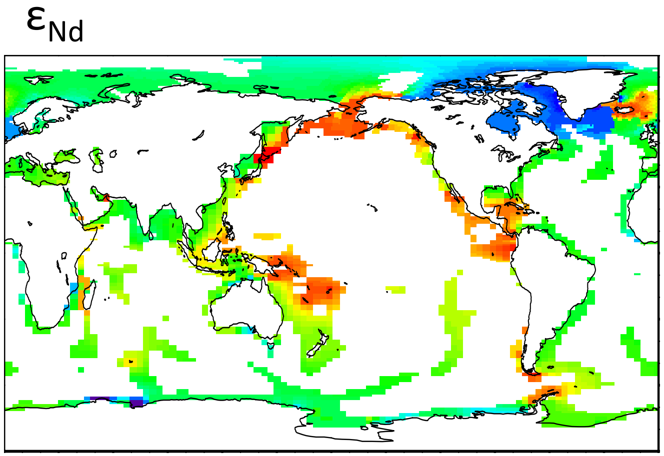
Nd modeling scheme: boundary source

$$S_{boundary} = f_{boundary} \times \frac{A}{A_{total}} \times \frac{1}{V}$$

Upper 3000 m

The boundary source per unit area is assumed to be constant with depth and globally uniform

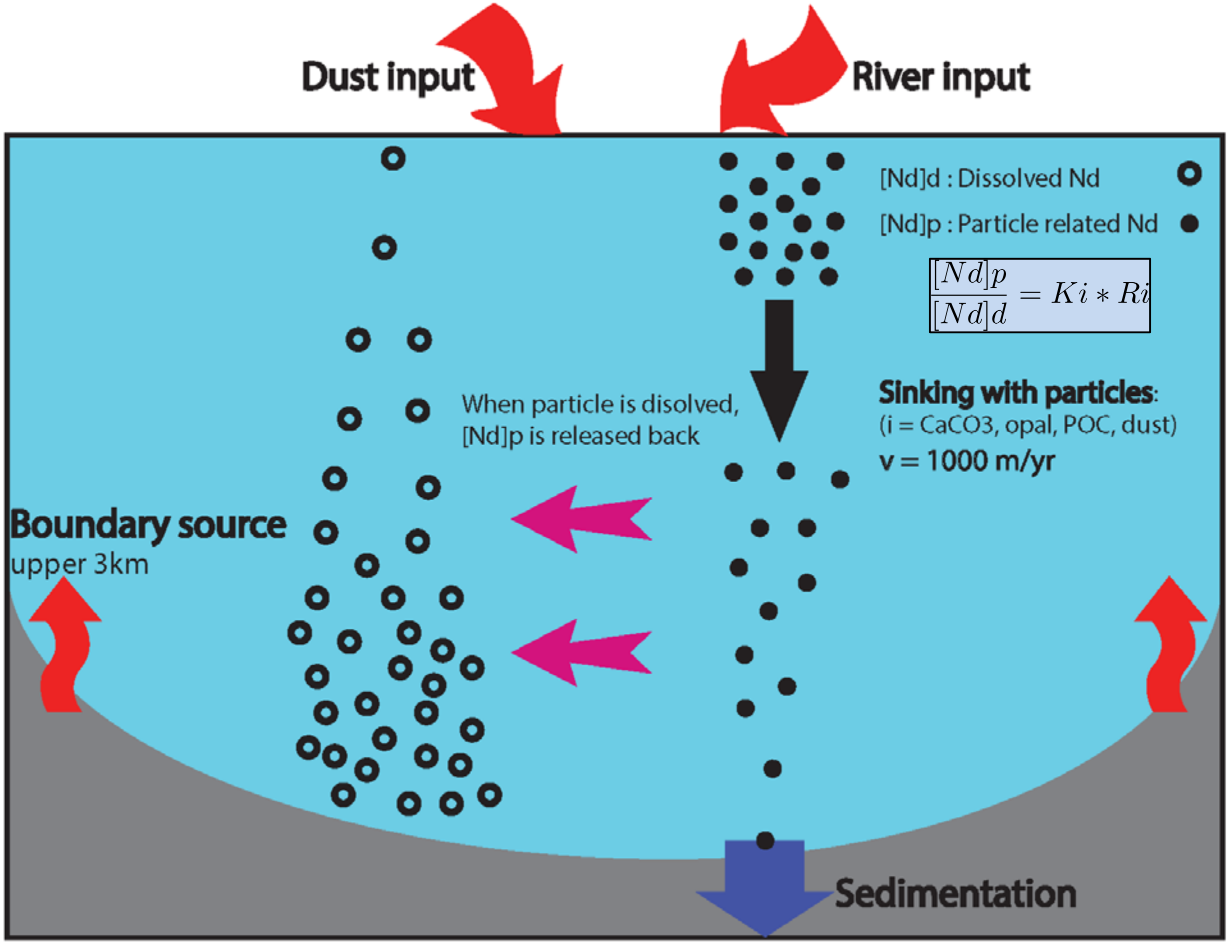
$f_{boundary}$: total boundary source (tuning parameter)
A_{total}: total sediment surface of the continental margins
A: grid area
V: grid volume



Jeandel et al., 2007

Nd modeling scheme: internal cycling

Reversible Scavenging: the physical process of adsorption and desorption of Nd on particle surfaces (previously used in Pa/Th modeling, e.g. Siddall et al. 2005)

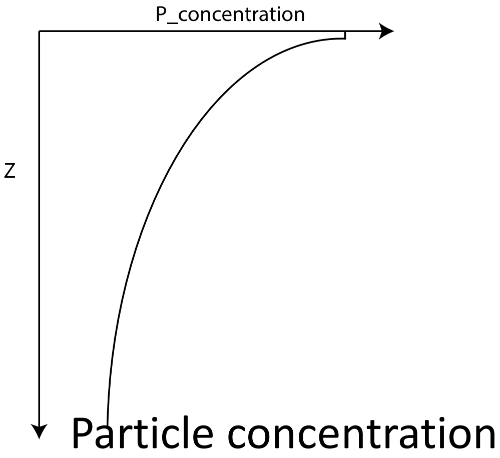


Ri: ratio between particle concentration and average density of water

Ki: equilibrium scavenging coefficient

$$K_i = (\frac{[Nd]_p}{[Nd]_d})_{avg} * \frac{1}{R_{i,avg}}$$

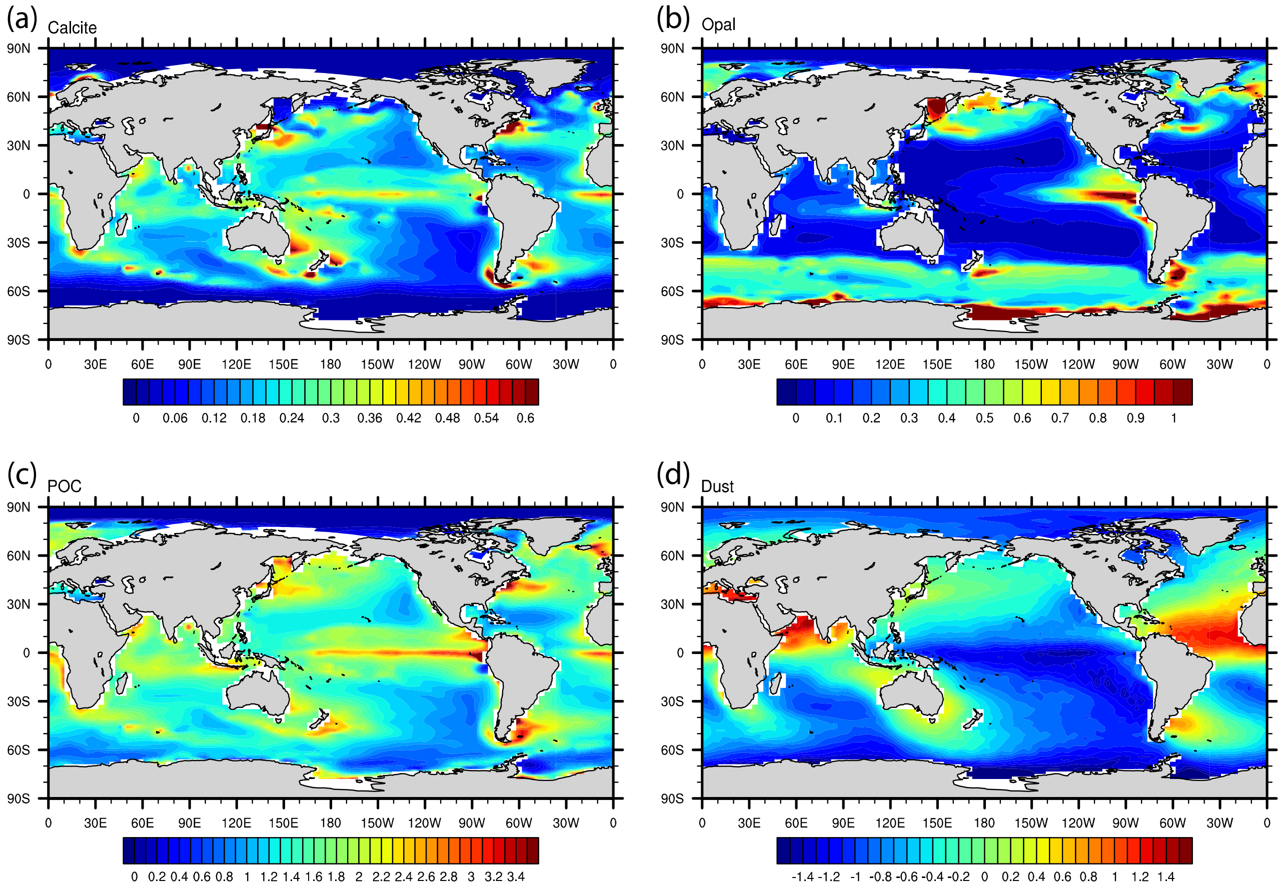
$$(\frac{[Nd]_p}{[Nd]_d})_{avg}$$ tuning parameter



$$S_{rs} = \frac{\partial v \cdot [Nd]_p^i}{\partial z}$$

Nd modeling scheme: internal cycling

Particle fields used in internal cycling {
- prescribed (abio_Nd)
- ecosystem (bio_Nd)



Annual mean particle fluxes at 105m in CESM

Parameters tuning for Nd (abio_Nd)

- Parameters: $f_{boundary}$ and $(\frac{[Nd]_p}{[Nd]_d})_{avg}$ (total 99 sets of experiments)
- Cost function:

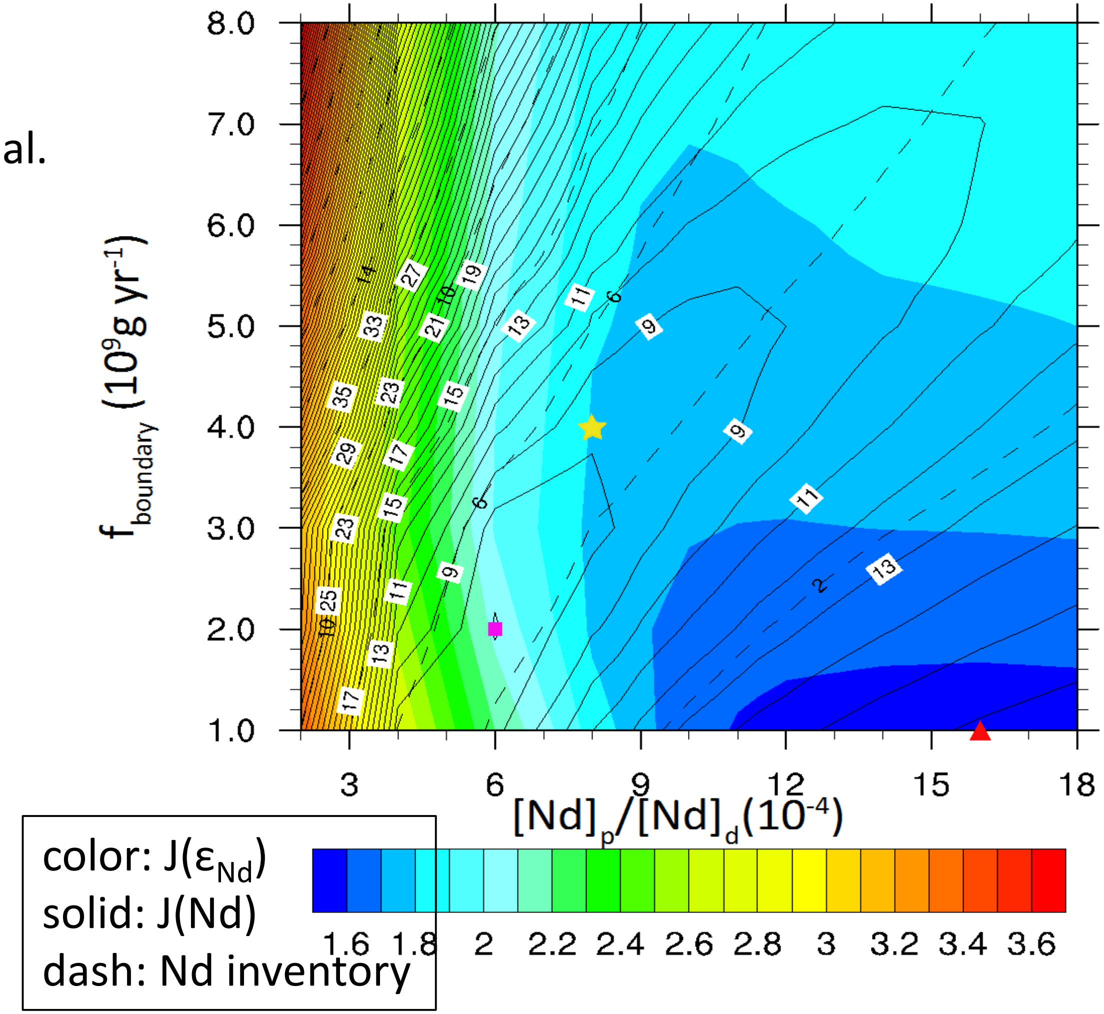
$$J = \frac{1}{N}\sum_{k=1}^{N} |obs_k - model_k|$$

- Observation from van de Flierdt et al. 2016 (larger dataset than used in Rempfer et al. 2011)

- ■ J(Nd) minimum
  ▲ $J(\varepsilon_{Nd})$ minimum
  ★ Control:

$f_{bounday} = 4×10^9$

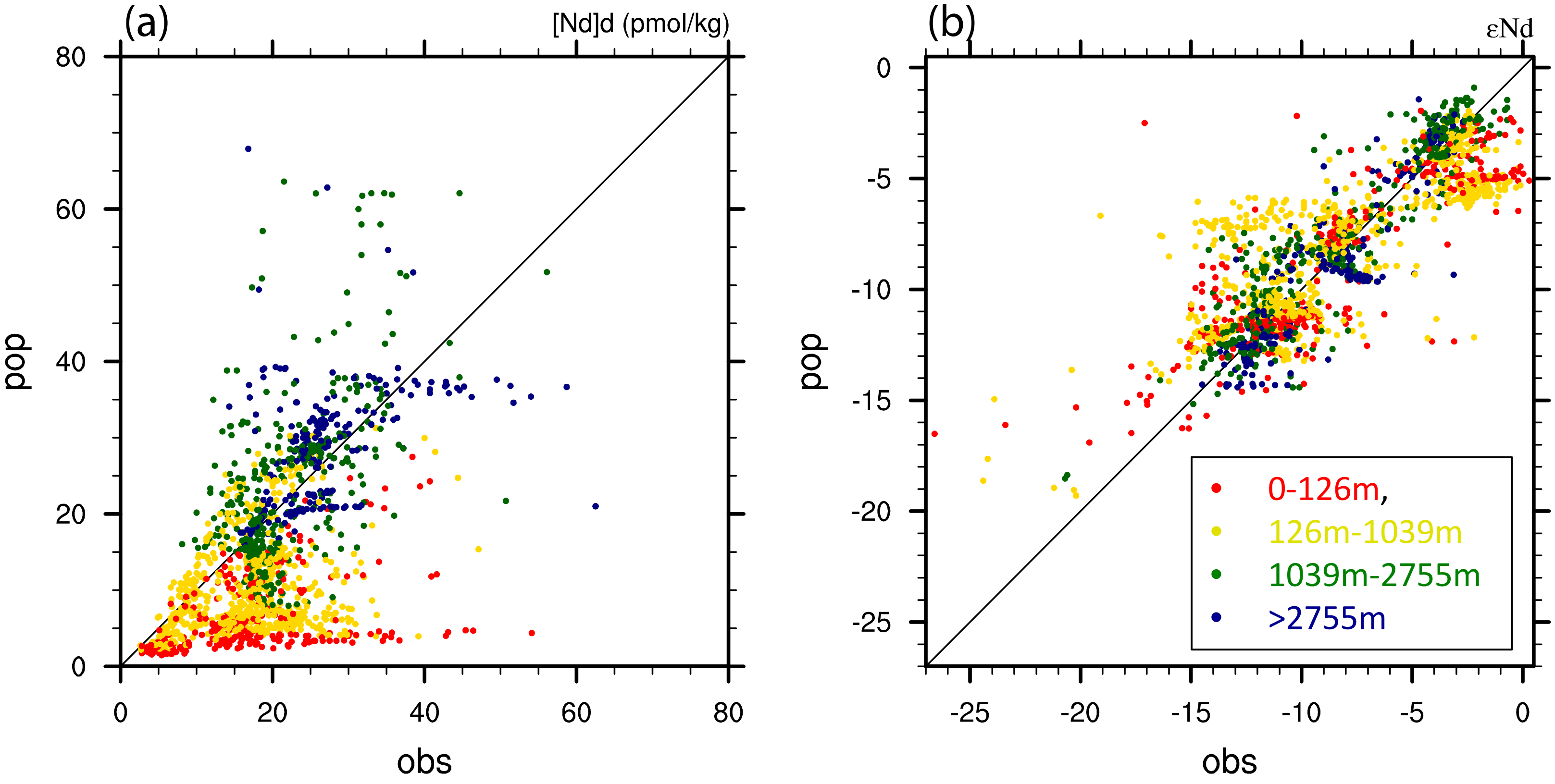
$(\frac{[Nd]_p}{[Nd]_d})_{avg} = 9×10^{-4}$



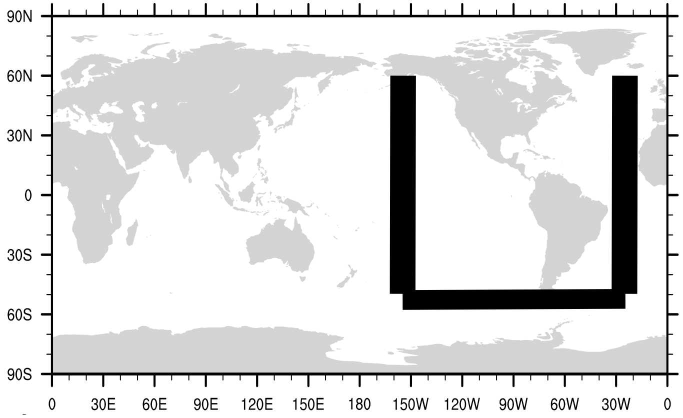
color: $J(\varepsilon_{Nd})$
solid: J(Nd)
dash: Nd inventory

Results: Control

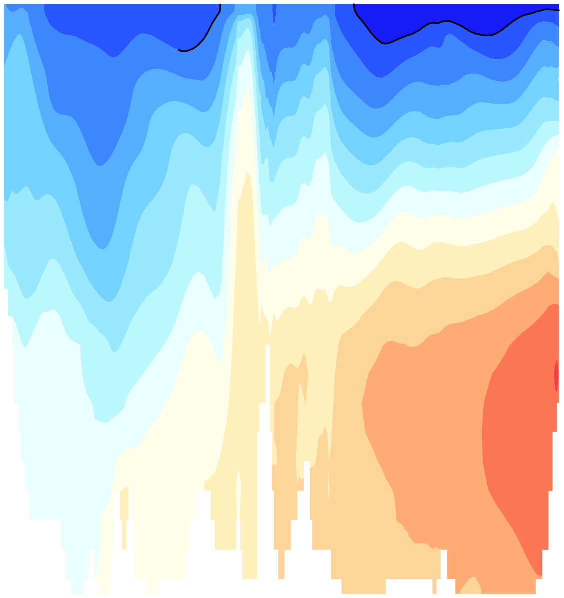
Nd inventory: 4.3×10^{12} g (4.2×10^{12} g from Arsouze et al., 2009; Tachikawa et al., 2003)
Residence time τ_{Nd} 785 yr (in the range of estimation by Tachikawa et al. 2003)



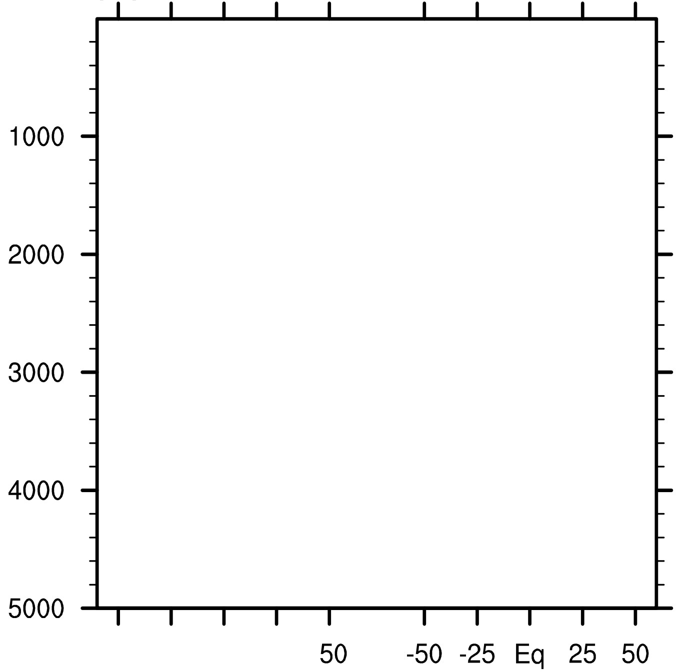
Results: Control (Track from Atlantic to Pacific)



(a) Nd

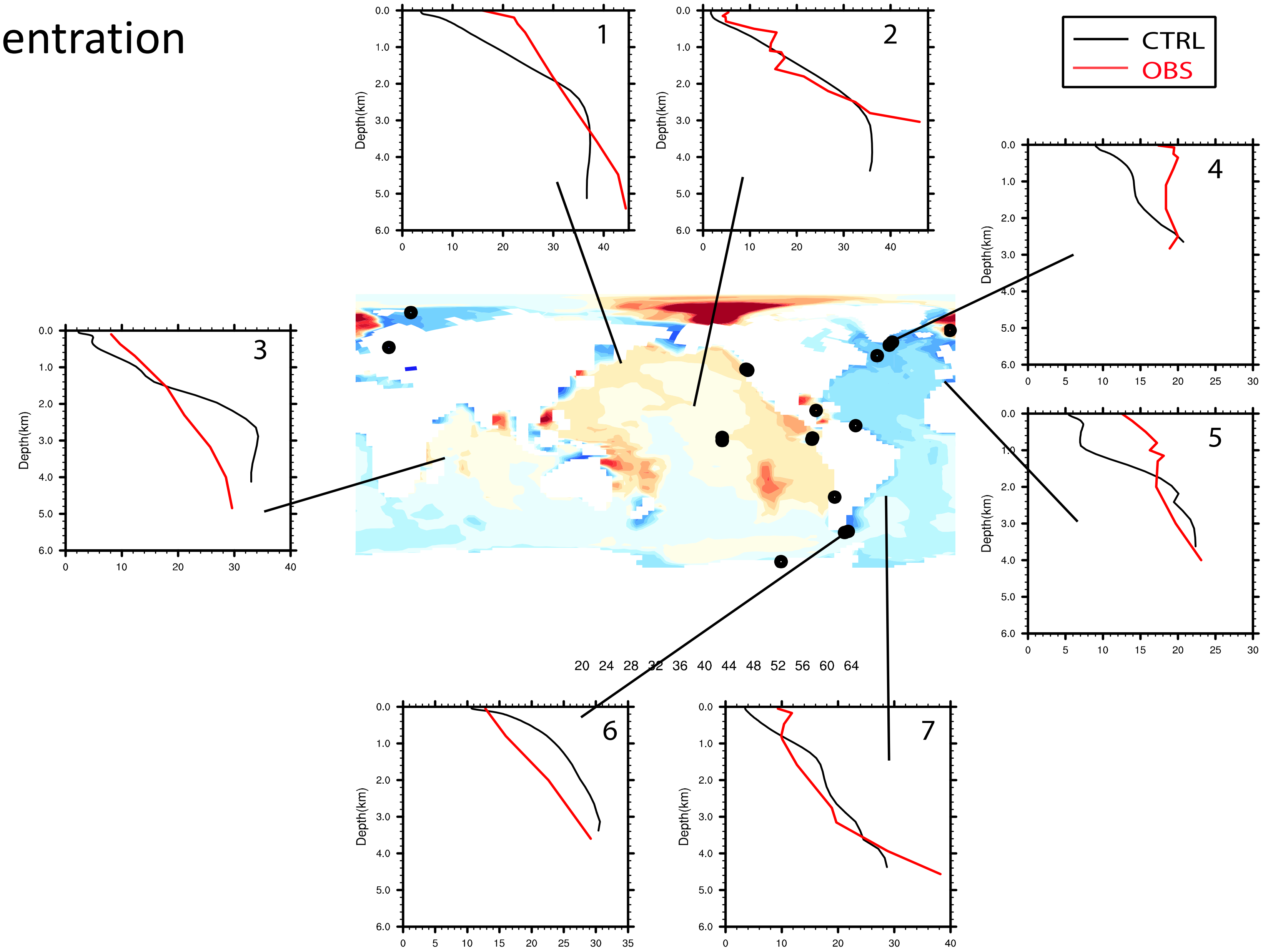


(b) ε_{Nd}



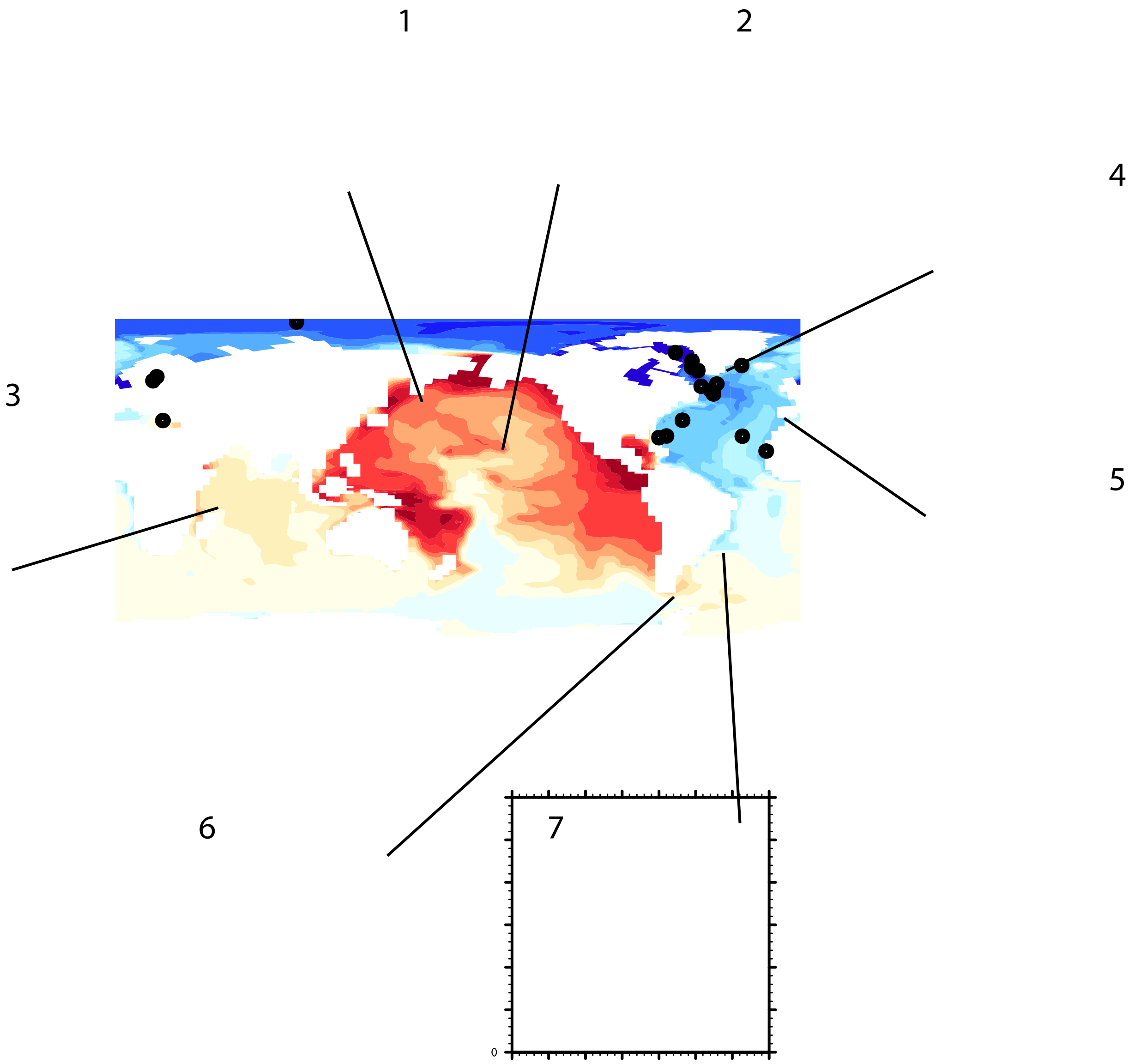
Results: Control (Seafloor & selected vertical profiles)

Nd concentration

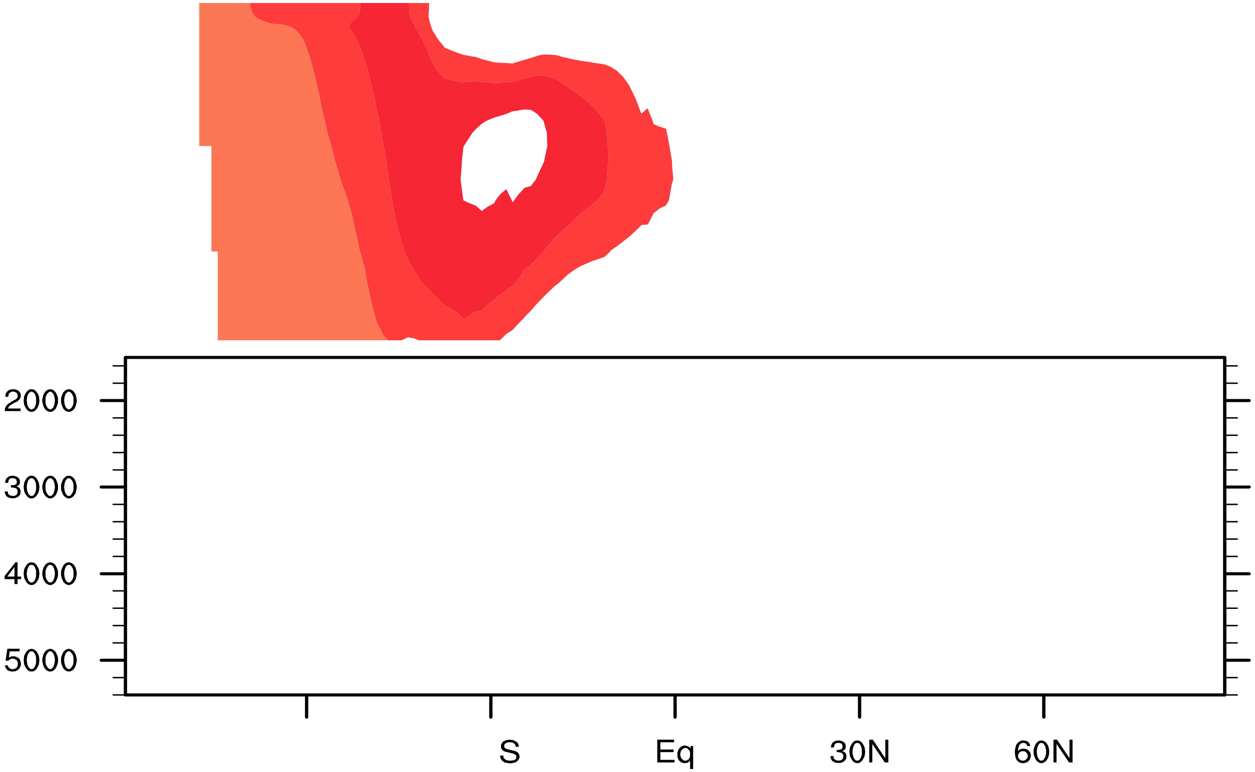


Results: Control (Seafloor & selected vertical profiles)

ε_{Nd}



Results: Control



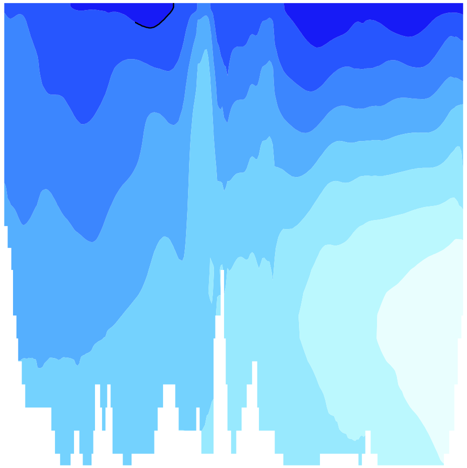
Atlantic zonal mean ε_{Nd} (color) and salinity (contour)

Results: Sensitivity on $f_{boundary}$

Nd

ε_{Nd}

$f_{boundary}/2$



$f_{boundary}*2$

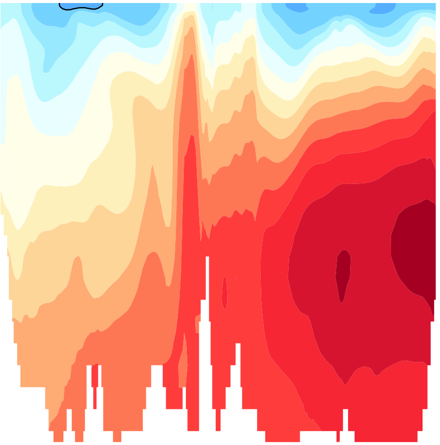
Results: Sensitivity on $[Nd]_p/[Nd]_d$

Nd

ε_{Nd}

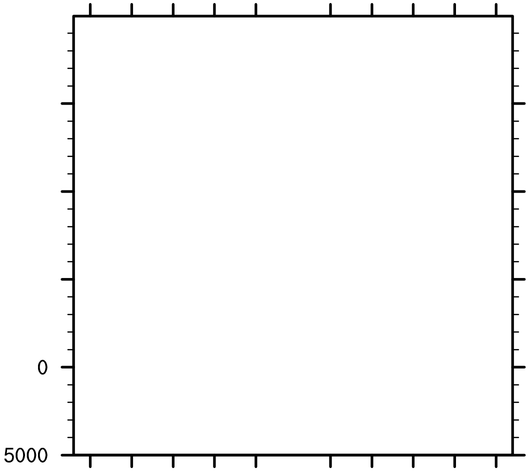
τ_{Nd}

$(\frac{[Nd]_p}{[Nd]_d})_{avg}$ /2



1680yr

$(\frac{[Nd]_p}{[Nd]_d})_{avg}$ *2



400yr

Summary

- Following Rempfer et al. 2011, we implement Nd isotopes in CESM and with the parameters tuned under present-day climate forcing, our model is able to simulate global distribution of both Nd concentration and ε_{Nd}, with reasonable agreement with the observation.
- Nd concentration and ε_{Nd} in our model shows similar sensitivities to the total boundary source and ratio of particle related Nd to dissolved Nd as in previous modeling study (Rempfer et al., 2011)
- Nd has both abiotic version (computational efficient) and biotic version. Comparing these two versions can help to separate the effect of circulation change and particle fields change on Nd.
- This Nd model provides a useful tool to study past changes of ocean and climate.

Thanks

- Isotope ratio: $^{143}Nd/^{144}Nd$

$$\epsilon_{Nd} = [\frac{(\frac{^{143}Nd}{^{144}Nd})_{sample}}{(\frac{^{143}Nd}{^{144}Nd})_{bulkEarth}} - 1] \times 10^4$$

$(^{143}Nd/^{144}Nd)_{\text{bulk Earth}}$ is 0.512638

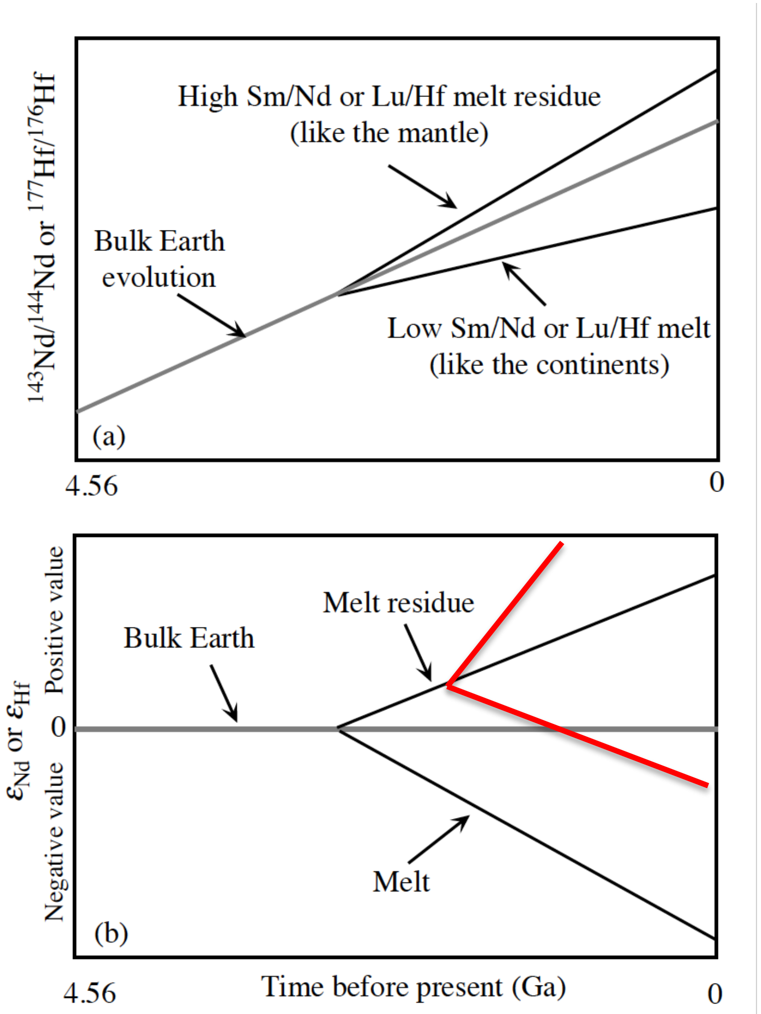
- Decay system: $^{147}Sm \rightarrow ^{143}Nd$

  $\lambda^{147}Sm = 6.54 \times 10^{-12}\ yr^{-1}$,

  Slow relative to 4.56Gyr age of solar system

- Nd is more likely to enter magma than Sm:

Younger continent, larger ε_{Nd}



Goldstein et al. 2003

Exp	$\frac{[Nd]_p}{[Nd]_d}$	f_{boundary} (g yr^{-1})	Inventory (g)	τ_{Nd} (yr)	$J_{[\mathrm{Nd}]\mathrm{d}}$ (pmol kg^{-1})	$J\varepsilon_{\mathrm{Nd}}$	J_1 (%)	J_2 (%)
CTRL	0.0009	4×10^{9}	4.3×10^{12}	785	8.1	1.76	72	82
$J_{[\mathrm{Nd}]\mathrm{d}}$ min	0.0006	2×10^{9}	4.6×10^{12}	1282	6.9	2.07	79	76
$J\varepsilon_{\mathrm{Nd}}$ min	0.0016	1×10^{9}	0.9×10^{12}	351	16.2	1.53	19	90
BS05	0.0009	2×10^{9}	2.8×10^{12}	796	10.1	1.71	58	83
BS20	0.0009	8×10^{9}	8.0×10^{12}	843	15.3	1.83	45	81
PD05	0.0004	4×10^{9}	9.3×10^{12}	1680	18.7	2.5	26	70
PD20	0.0018	4×10^{9}	2.2×10^{12}	400	14.4	1.88	42	80
CTRL_R	0.001	5.5×10^{9}	5.1×10^{12}	720	9.3	1.78	64	83
CTRL_R*	0.001	5.5×10^{9}	4.2×10^{12}	700	9	1.66	70	83
EXP1	0.0008	5×10^{9}	6.02×10^{12}	915	9.8	1.8	60	82
EXP2	0.0009	5×10^{9}	5.29×10^{12}	805	9.1	1.8	66	82
CTRL_old	0.0008	4×10^{9}	5.0×10^{12}	900	9.6	1.8	71	82