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

Goldstein et al. 2003
Introduction of Nd isotopes: $\varepsilon_{\text{Nd}}$

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

$$\varepsilon_{\text{Nd}} = \left[ \frac{^{143}\text{Nd}}{^{144}\text{Nd}} \right]_{\text{sample}} - 1 \right] \times 10^4$$

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

- Younger continent, larger (more radiogenic) $\varepsilon_{\text{Nd}}$
- Older continent, smaller $\varepsilon_{\text{Nd}}$

- $\varepsilon_{\text{Nd}}$ as water-mass mixing tracer:
  - AAIW: ~-8 - -9
  - AABW: ~-9
  - NADW: ~-13 - -14

- Biological fractionation of Nd is negligible
- $\varepsilon_{\text{Nd}}$ has been increasingly used in paleoceanography

Albare & Goldstein, 1992

von Blanckenburg, 1999
Nd modeling scheme

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

\[ ^{143}\text{Nd} \text{ and } ^{144}\text{Nd are two separate tracers} \]

**Sources:** River, Dust & Boundary

**Sink:** Sedimentation

**Internal Cycling:** reversible scavenging
Nd modeling scheme: dust source

\[ S_{\text{dust}} = F_{\text{dust}} \times c_{\text{dust}} \times \beta_{\text{dust}} \times \frac{1}{\Delta z_1} \]

- \( F_{\text{dust}} \): surface dust flux
- \( c_{\text{dust}} \): global mean Nd concentration in dust, 20 \( \mu g/g \), \textit{Grousset et al., 1998}
- \( \beta_{\text{dust}} \): Nd release from dust, 20\%, \textit{Greaves et al., 1994}
- \( \Delta z_1 \): thickness of first ocean layer

\textit{Mahowald et al., 2005}

\textit{Tachikawa et al., 2003}
$S_{river} = F_{river} \times c_{river} \times (1 - \gamma_{dust}) \times \frac{1}{\Delta z_1}$

$F_{river}$: river runoff, from coupler  
$c_{river}$: global mean Nd concentration in river  
$\gamma_{dust}$: estuaries Nd removal,  
0.7, *Elderfield et al., 1990*  
$\Delta z_1$: thickness of first ocean layer
Nd modeling scheme: boundary source

\[ S_{\text{boundary}} = f_{\text{boundary}} \times \frac{A}{A_{\text{total}}} \times \frac{1}{V} \]

Upper 3000 m

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

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

Jeandel et al., 2007
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

\[ K_i = \left( \frac{[Nd]_p}{[Nd]_d} \right)_{avg} \times \frac{1}{R_i,avg} \]

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

Nd modeling scheme: internal cycling

\[ S_{rs} = \frac{\partial v \cdot [Nd]^i_p}{\partial z} \]
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: $f_{\text{boundary}}$ and $\left(\frac{[Nd]_p}{[Nd]_d}\right)_{\text{avg}}$
- Cost function:
  \[ J = \frac{1}{N} \sum_{k=1}^{N} |\text{obs}_k - \text{model}_k| \]
- Observation from van de Flierdt et al. 2016 (larger dataset than used in Rempfer et al. 2011)
- **J(Nd) minimum**
- **J(\epsilon_{Nd}) minimum**
- **Control:**
  \[ f_{\text{boundary}} = 4 \times 10^9 \]
  \[ \left(\frac{[Nd]_p}{[Nd]_d}\right)_{\text{avg}} = 9 \times 10^{-4} \]
Results: Control

Nd inventory: $4.3 \times 10^{12}$ g ($4.2 \times 10^{12}$ g from Arsouze et al., 2009; Tachikawa et al., 2003)

Residence time $\tau_{Nd}$ 785 yr (in the range of estimation by Tachikawa et al. 2003)
Results: Control (Track from Atlantic to Pacific)
Results: Control (Seafloor & selected vertical profiles)

Nd concentration

[Diagrams showing depth profiles and a map with data points]
Results: Control (Seafloor & selected vertical profiles)

$\varepsilon_{\text{Nd}}$
Results: Control

Atlantic zonal mean $\varepsilon_{\text{Nd}}$ (color) and salinity (contour)
Results: Sensitivity on $f_{\text{boundary}}$

$\frac{f_{\text{boundary}}}{2}$

$\frac{f_{\text{boundary}} \times 2}$
Results: Sensitivity on $[Nd]_p/[Nd]_d$

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

$\left( \frac{[Nd]_p}{[Nd]_d} \right)_{avg} \times 2$

$\varepsilon_{Nd}$

$\tau_{Nd}$

1680 yr

400 yr
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 $\varepsilon_{\text{Nd}}$, with reasonable agreement with the observation.

Nd concentration and $\varepsilon_{\text{Nd}}$ 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: $^{143}\text{Nd}/^{144}\text{Nd}$

$$
\epsilon_{\text{Nd}} = \left[ \frac{(^{143} \text{Nd}/^{144} \text{Nd})_{\text{sample}}}{(^{143} \text{Nd}/^{144} \text{Nd})_{\text{bulk Earth}}} - 1 \right] \times 10^4
$$

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

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

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

Slow relative to 4.56Gyr age of solar system

- Nd is more likely to enter magma than Sm:
  Younger continent, larger $\epsilon_{\text{Nd}}$

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Goldstein et al. 2003
<table>
<thead>
<tr>
<th>Exp</th>
<th>$[Nd]<em>{p}$/$[Nd]</em>{d}$</th>
<th>$f_{\text{boundary}}$ (g yr$^{-1}$)</th>
<th>Inventory (g)</th>
<th>$\tau_{Nd}$ (yr)</th>
<th>$J_{Nd}$ (pmol kg$^{-1}$)</th>
<th>$J_{\varepsilon_{Nd}}$ (%)</th>
<th>$J_{1}$ (%)</th>
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