Challenges of using noble gas isotope ratios for reconstructing mean global ocean temperatures, deep ocean circulation and Greenland temperature reconstruction

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Mean Ocean Temperature (MOT) reconstruction based on noble gases

**Atmosphere**

Today $\delta^{13} \text{Kr}/N_2 = \delta^{13} \text{Xe}/N_2 = \delta^{13} \text{Xe}/\text{Kr} = 0\%$  
LGM $\delta^{13} \text{Kr}/N_2 = -1.2\%; \delta^{13} \text{Xe}/N_2 = -3.7\%; \delta^{13} \text{Xe}/\text{Kr} = -2.5\%$

**Residual ocean**

Today $T = 7.5\; ^\circ C$; $V = 45\%$; $S = 34.7$
LGM $T = 5.4\; ^\circ C$; $V = 35\%$; $S = 35.9$

**AABW**

Today $T = -0.9\; ^\circ C$; $V = 35\%$; $S = 34.6$
LGM $T = -2.0\; ^\circ C$; $V = 50\%$; $S = 35.8$

**NADW**

$T = 2.3\; ^\circ C$; $V = 20\%$; $S = 34.9$
$LGM\ T = -0.8\; ^\circ C$; $V = 15\%$; $S = 36.1$

**Equator**

- $\text{Kr}/N_2$
  - $1\% \rightarrow 2^\circ C$
- $\text{Xe}/N_2$
  - $4\% \rightarrow 2.5^\circ C$
- $\text{Xe}/\text{Kr}$
  - $1\% \rightarrow 1^\circ C$

21 October 2019
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Ca. 2.5°C temperature change in the ocean from LGM to today
Ocean Deep Circulation based on noble gases

\[ \Delta \delta \text{ (per meg)} \]

\[ \Delta \text{K}_2/\text{Ar} \% \]

\[ \delta \% \]
Mean $\Delta \delta^{40/36}Ar$, $\Delta \delta^{38/36}Ar$, $\Delta \delta^{86/82}Kr$ below 2000 m are $-125 \pm 10$ per meg, $-64 \pm 13$ per meg, $-37 \pm 15$ per meg ($\pm 1$ standard error), respectively, where 1 per meg = 0.001‰ = 0.0001%.

Deep-ocean mean $\Delta \delta^{136/129}Xe$ is $-2 \pm 25$ per meg. While uncertainties prevent meaningful interpretation of this small value, we suggest that future gains in analytical precision and large-volume sampling campaigns could resolve Xe isotopic disequilibria at the single per meg level.
Temperature reconstruction based on nitrogen and argon isotopes from ice cores

For $\delta^{15}$N

- $10^\circ$C $\rightarrow$ 0.15 permil or 150 per meg
- $1^\circ$C $\rightarrow$ 15 permeg

$\rightarrow$ 8.2 kyr cooling
$\rightarrow$ 3.5°C