Decoupling of Late Paleozoic epicontinental sea and ocean $\delta^{18}O$ in iCESM

NCAR Paleoclimate Working Group Meeting 2019

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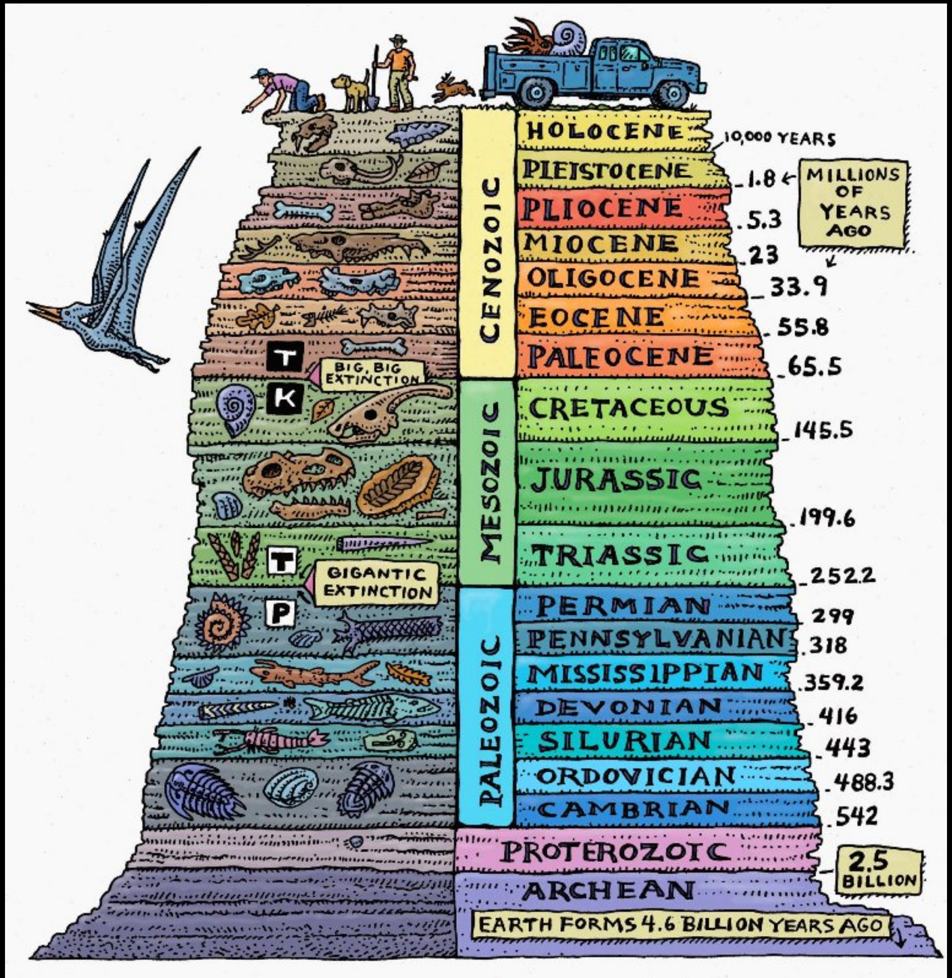
Introduction: Late Paleozoic Ice Age



- Icehouse periods make up <25% of the past billion years, yet glacial-interglacial cycles persisted for ~70 Ma of the Paleozoic (Montañez & Poulsen, 2013)

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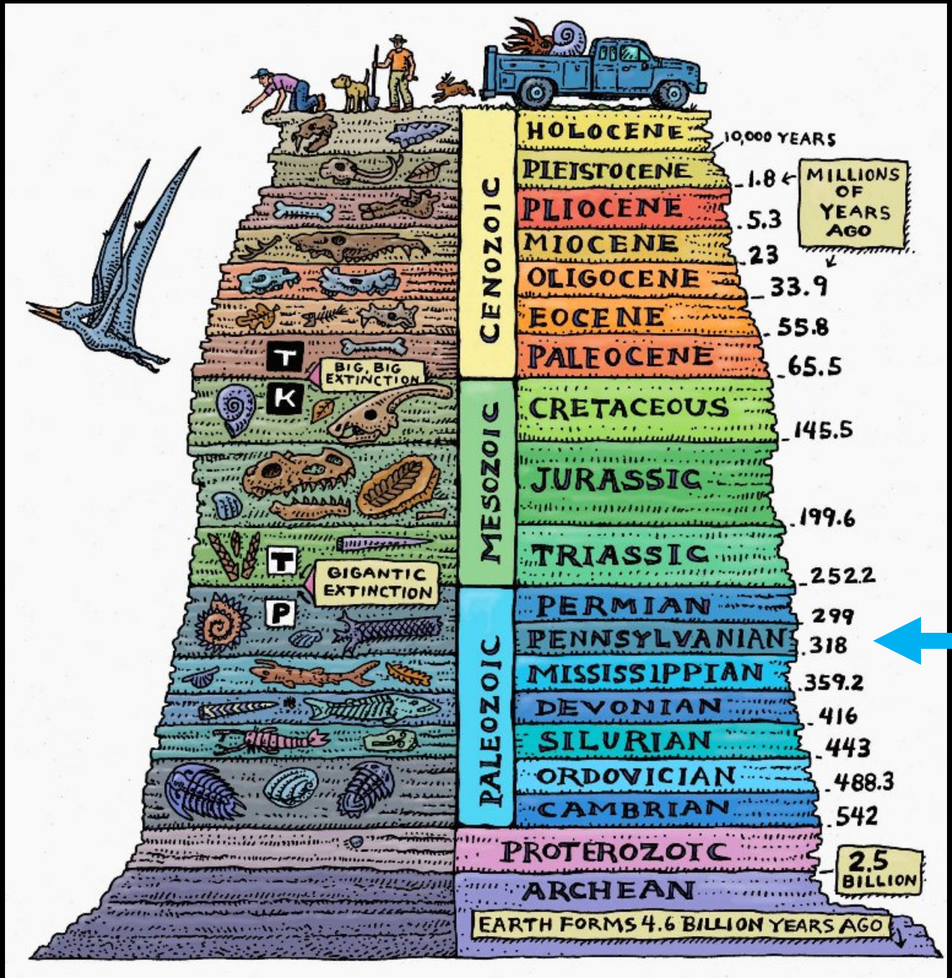


- Icehouse periods make up <25% of the past billion years, yet glacial-interglacial cycles persisted for ~70 Ma of the Paleozoic (Montañez & Poulsen, 2013)

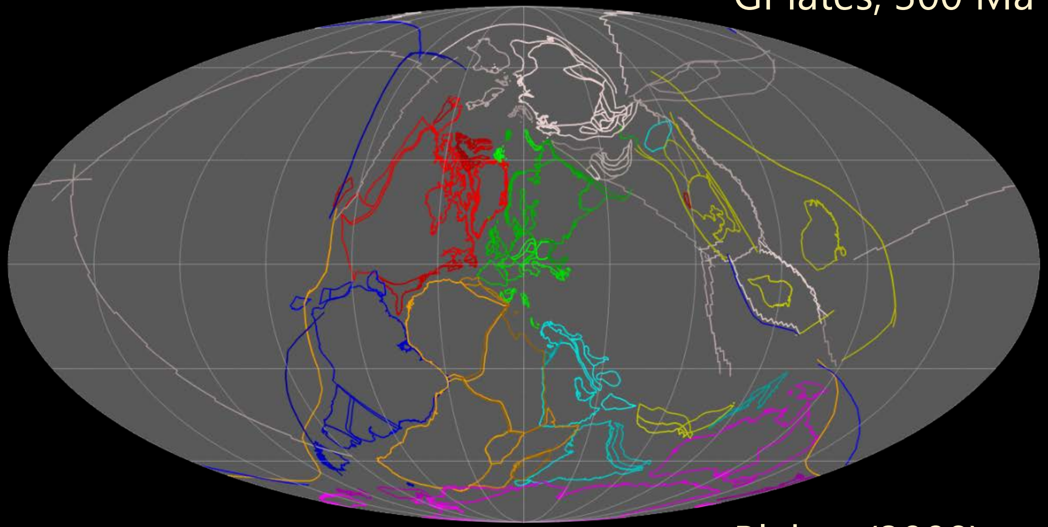
Pennsylvanian

Introduction: Seawater reconstructions

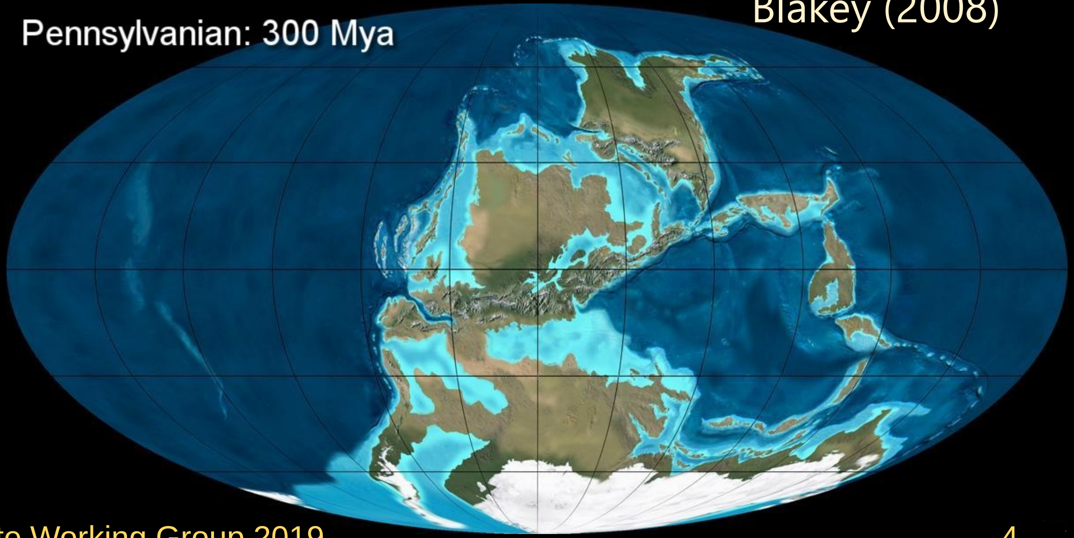
- Mean paleo-seawater conditions, especially pre-Mesozoic, largely inferred from epicontinental seas
  - Shallow carbonate platforms and interior sea successions

- Assume that ancient ocean chemistry is coupled to epicontinental seawater isotope records ($\delta^{18}O_{sw}$ = ~0‰)

GPlates, 300 Ma



Blakey (2008)



Introduction: Seawater reconstructions

- Mounting geologic evidence for the overprinting of local processes on global trends in epicontinental records
  - Shallow depths and limited communication with the open ocean cause high variability in seawater conditions (Montañez et al., 2018; Joachimski & Lambert, 2015; Roark et al., 2017; Brand et al., 2009)

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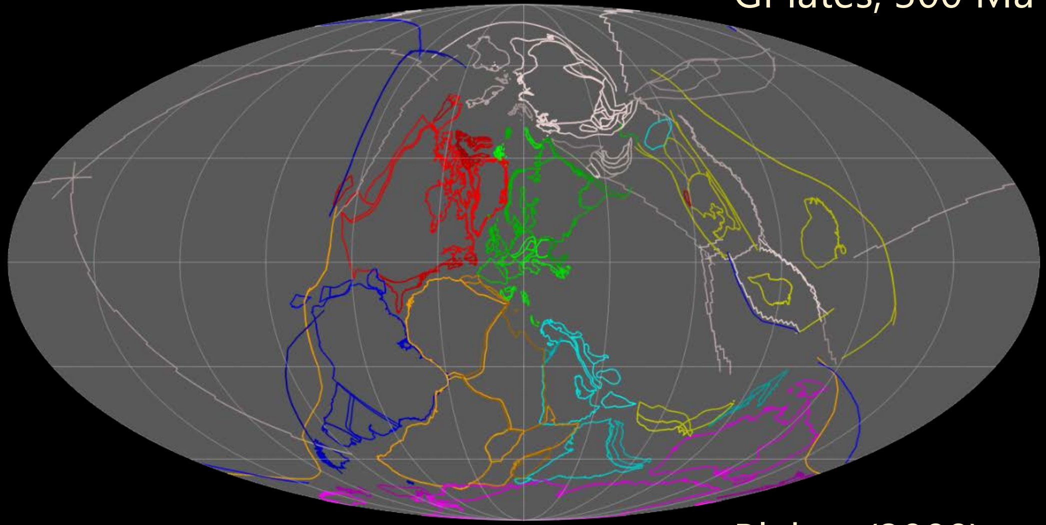

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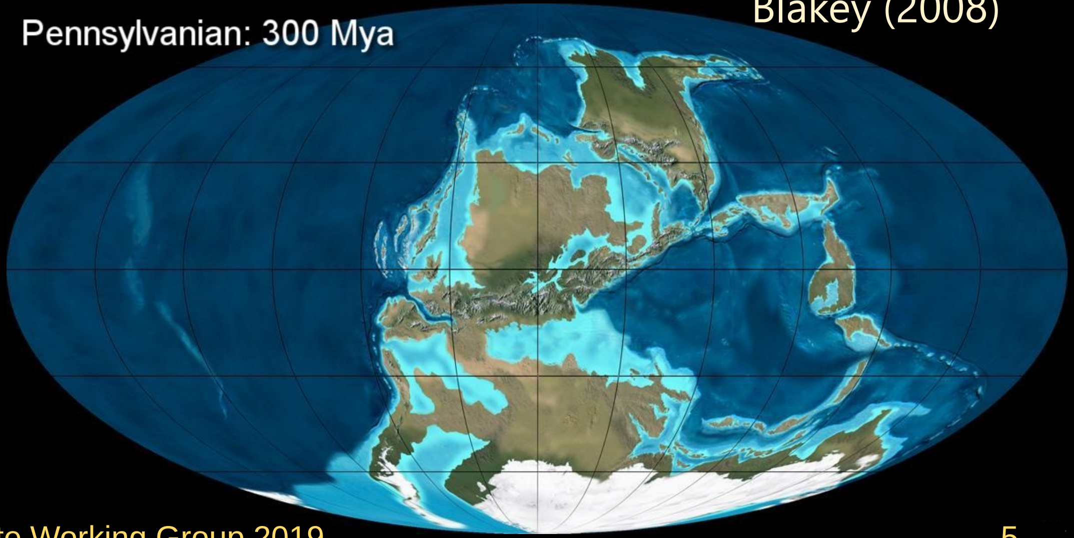

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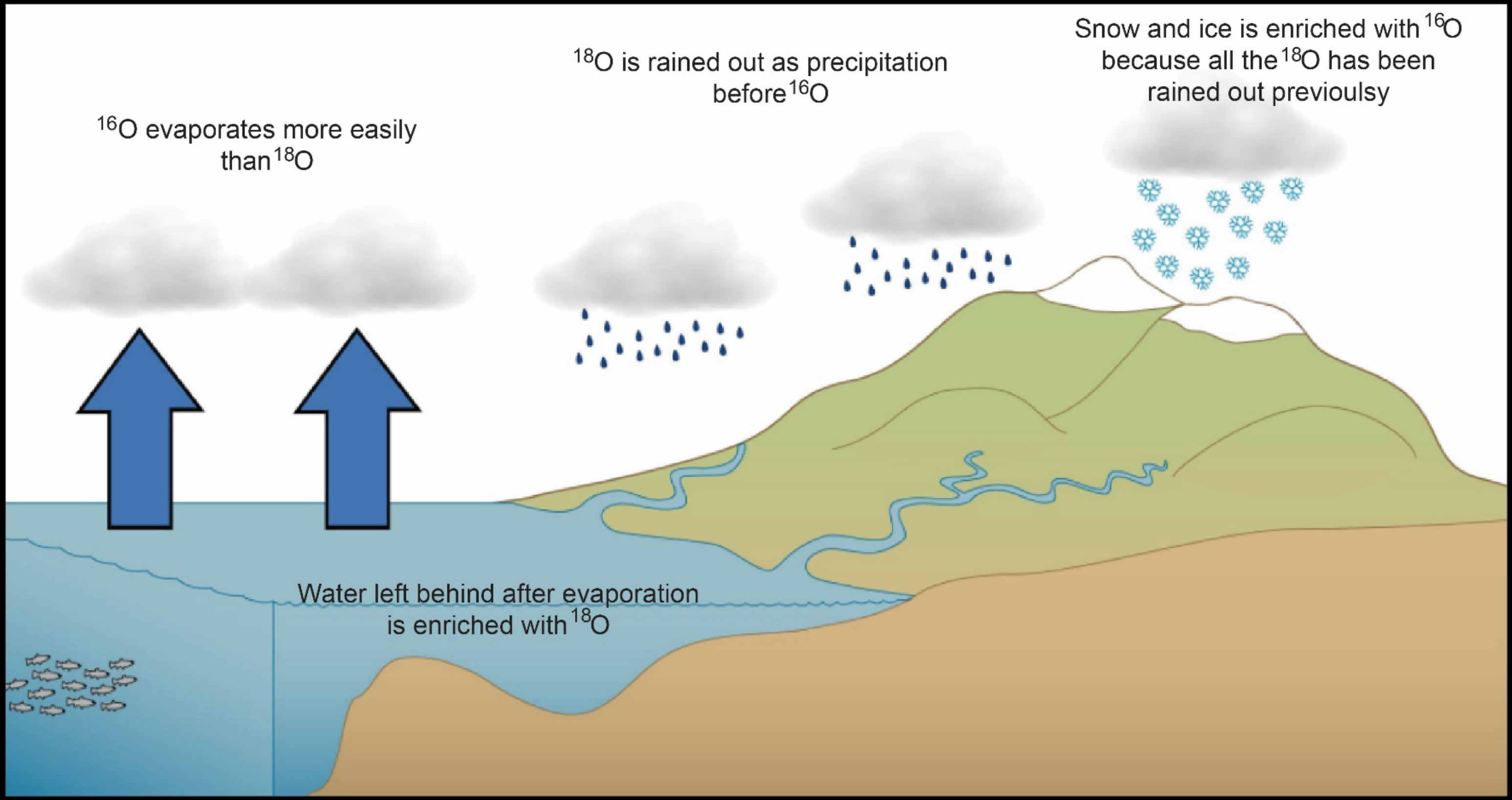
Introduction: $\delta^{18}O$ of seawater



- Evaporation: ↑$\delta^{18}O$
- Precipitation and runoff: ↓$\delta^{18}O$

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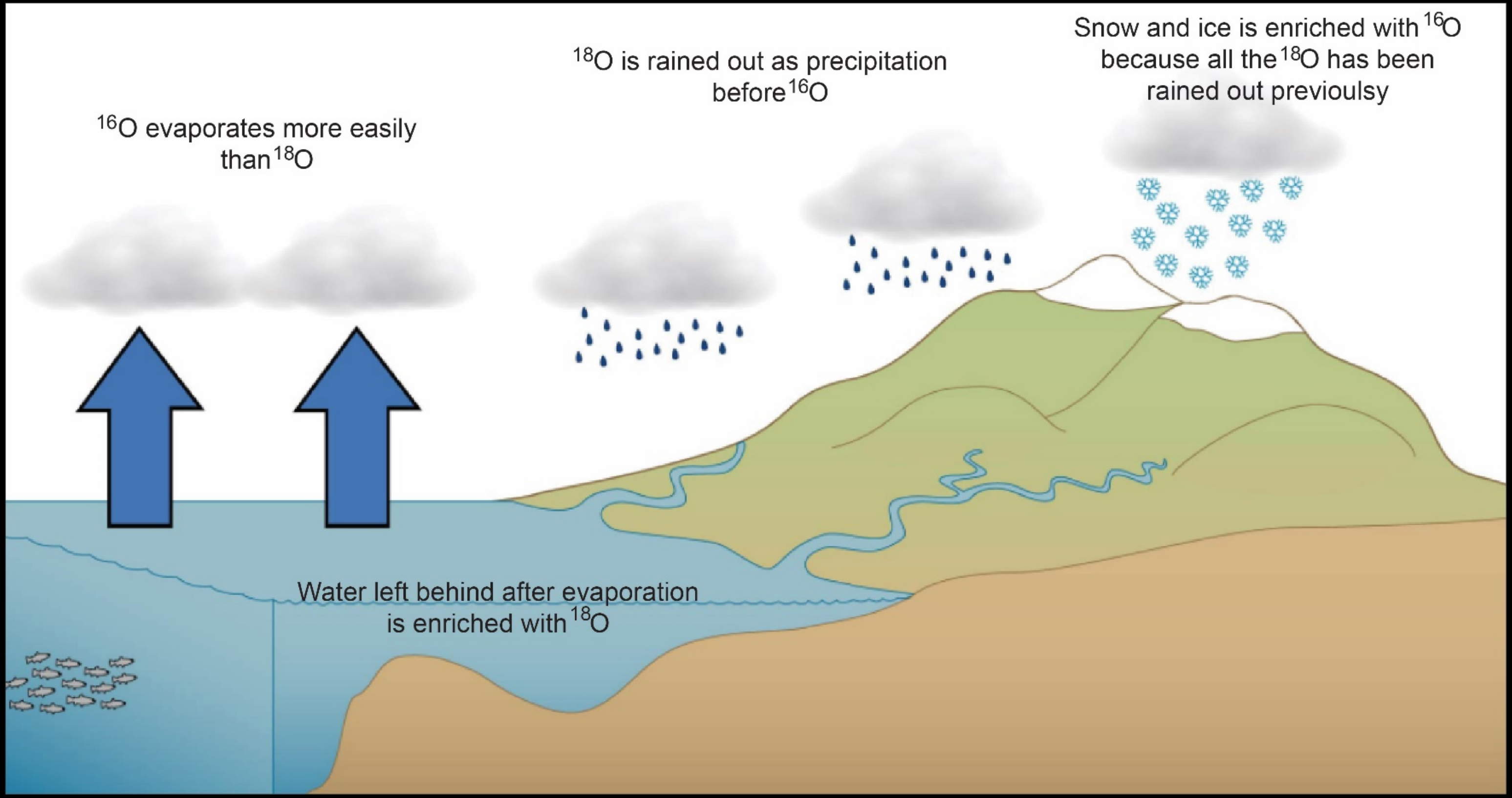


- Evaporation: $\uparrow\delta^{18}O$
- Precipitation and runoff: $\downarrow\delta^{18}O$

- Ice sheet growth: $\uparrow\delta^{18}O$
- Ice sheet melt: $\downarrow\delta^{18}O$

Goals of the present study

1. Present the first simulations of Late Paleozoic glacial and interglacial states that resolve epicontinental sea dynamics

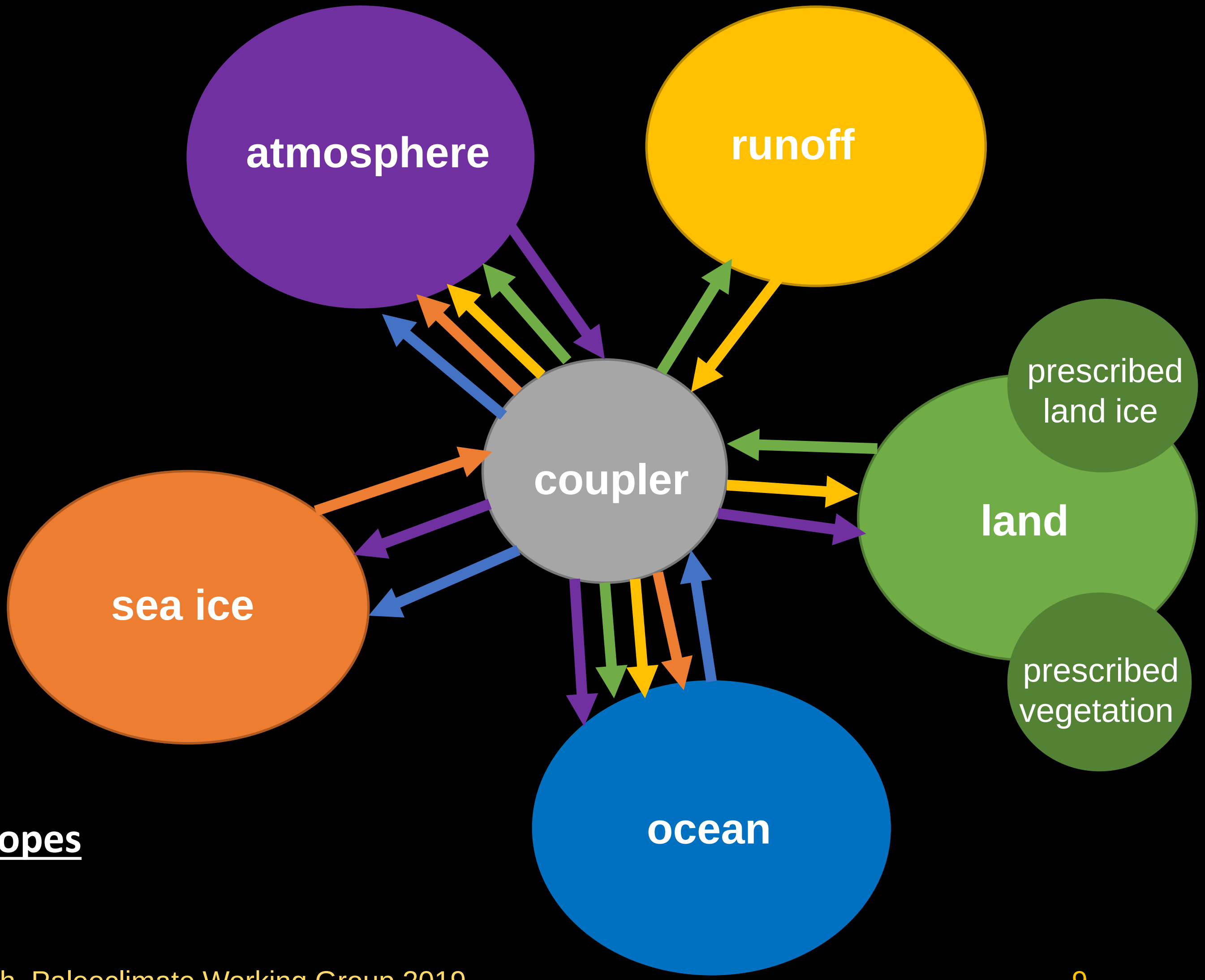
2. Investigate what processes influence seawater $\delta^{18}O$ in epicontinental seas, and whether these environments are coupled to mean ocean conditions

3. Compare simulations with published geochemical proxy data to constrain seawater $\delta^{18}O$ in the Midcontinent sea

Methods: iCESM1 setup

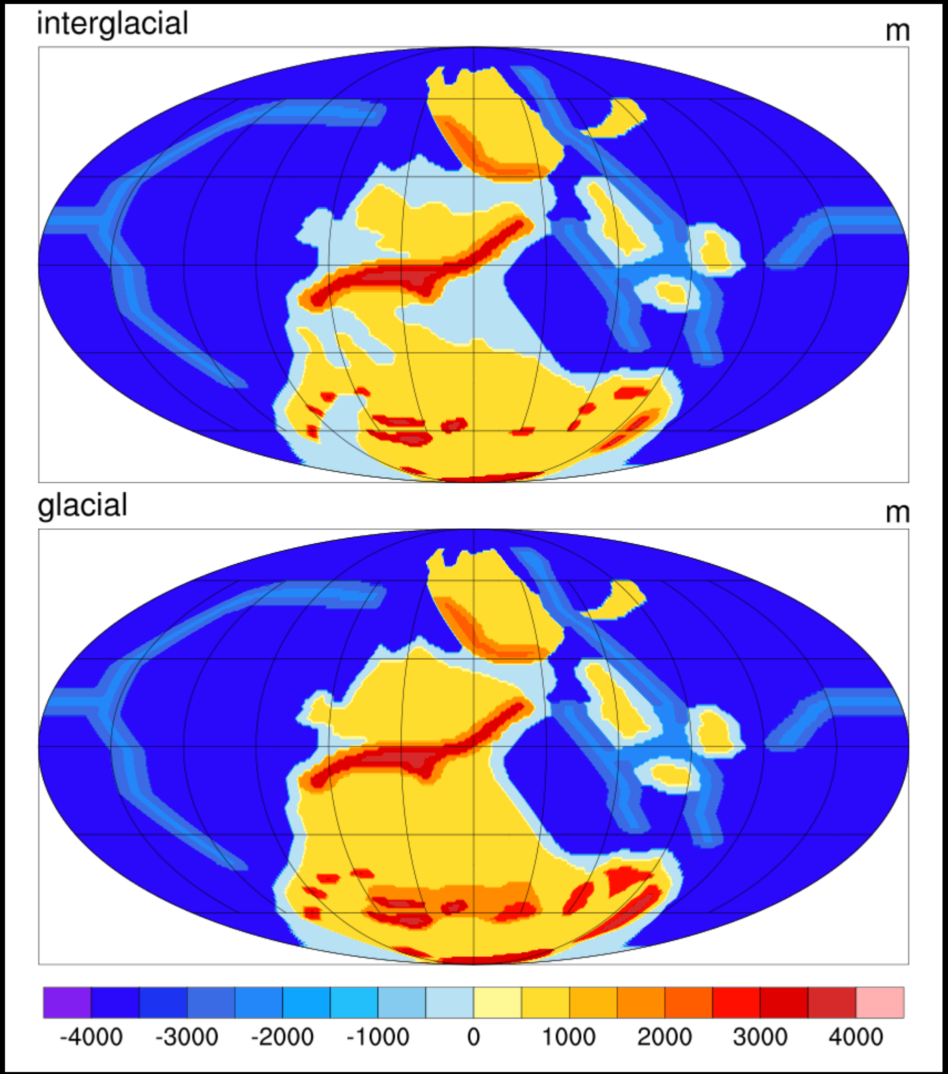
- CAM5 and CLM4 (1.9º x2.5º)
- POP2 and CISM4 (~1º)

Water Isotopes



Methods: Base simulations

Case	Glacial	Interglacial
Runtime	2000 years	2000 years
Paleogeography	300 Ma Low sea level/ High land ice	300 Ma High sea level/ Low land ice
Atmospheric [CO_2]	280 ppmv	560 ppmv
Solar luminosity	97.5% modern	97.5% modern
Initial $\delta^{18}O$ ocean	0.5‰	0‰



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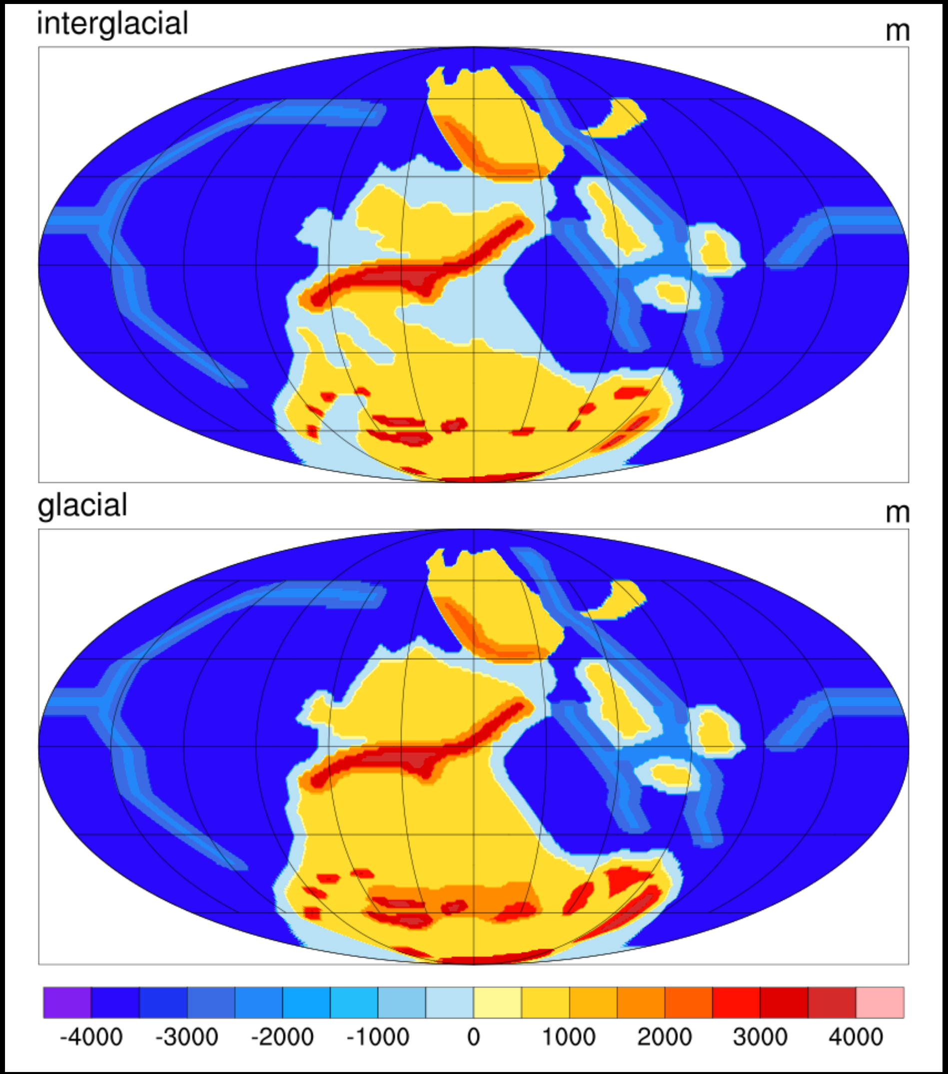
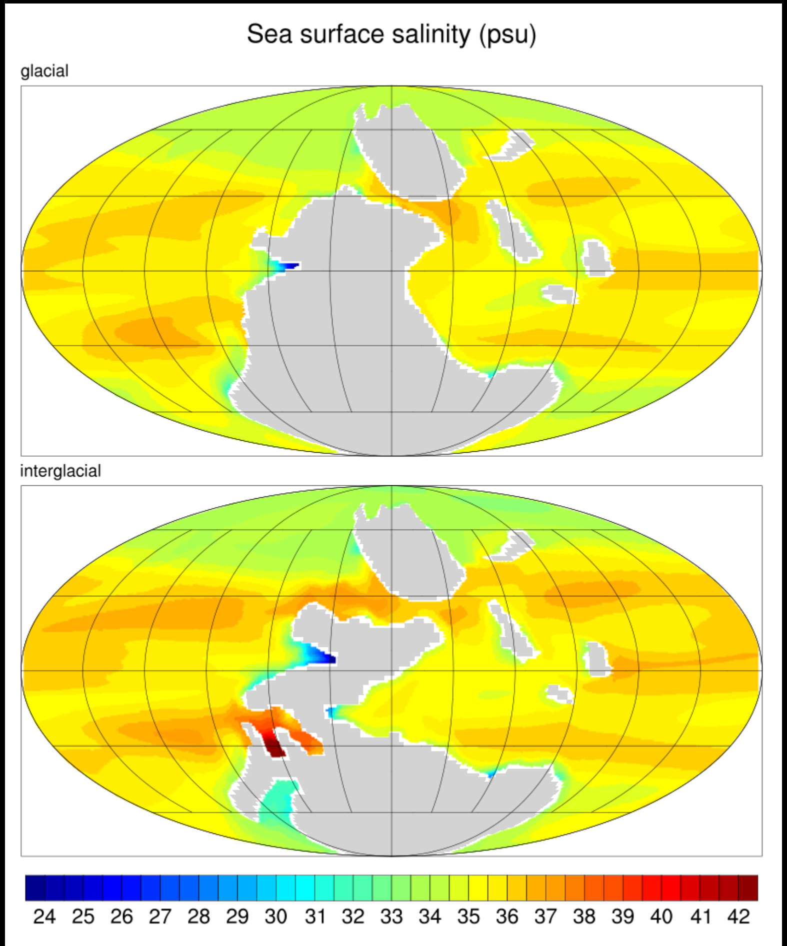
*Differences between two simulations



Results: Mean annual SSS



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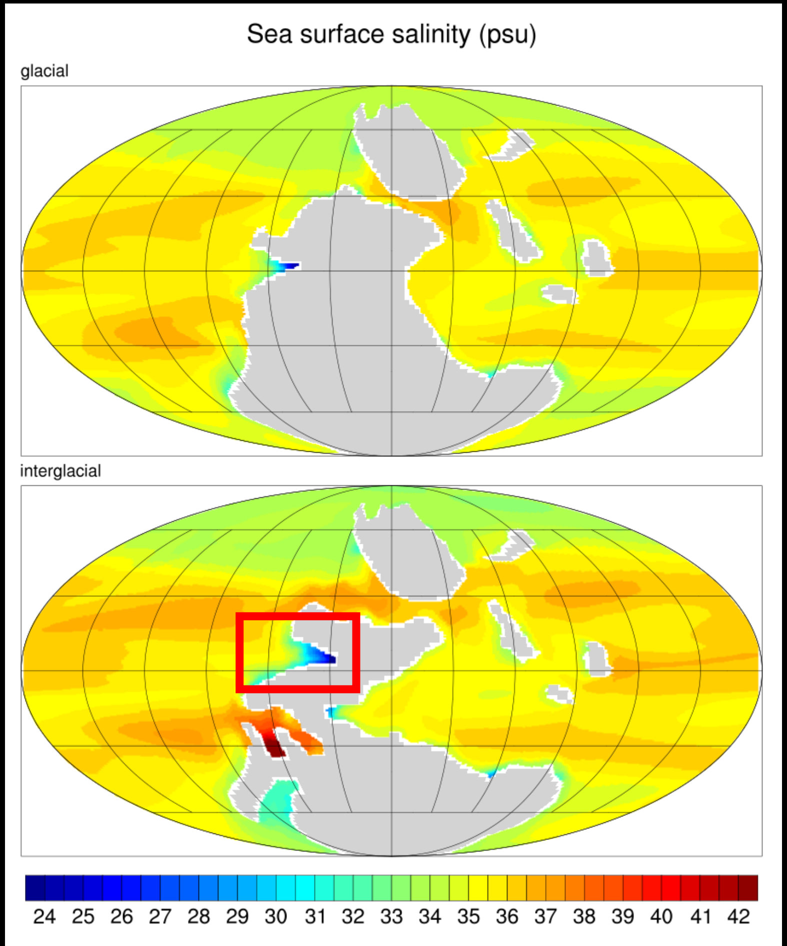
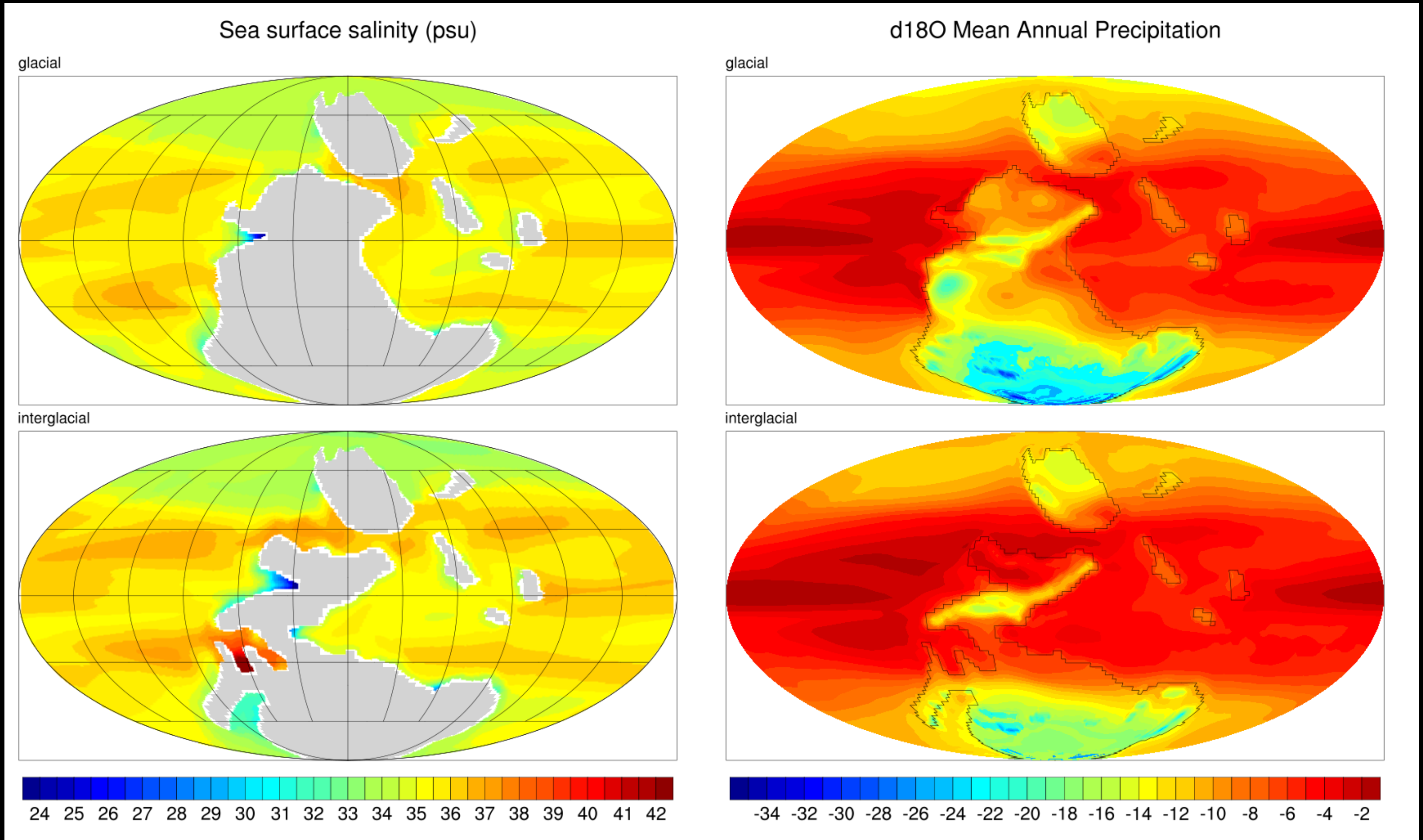


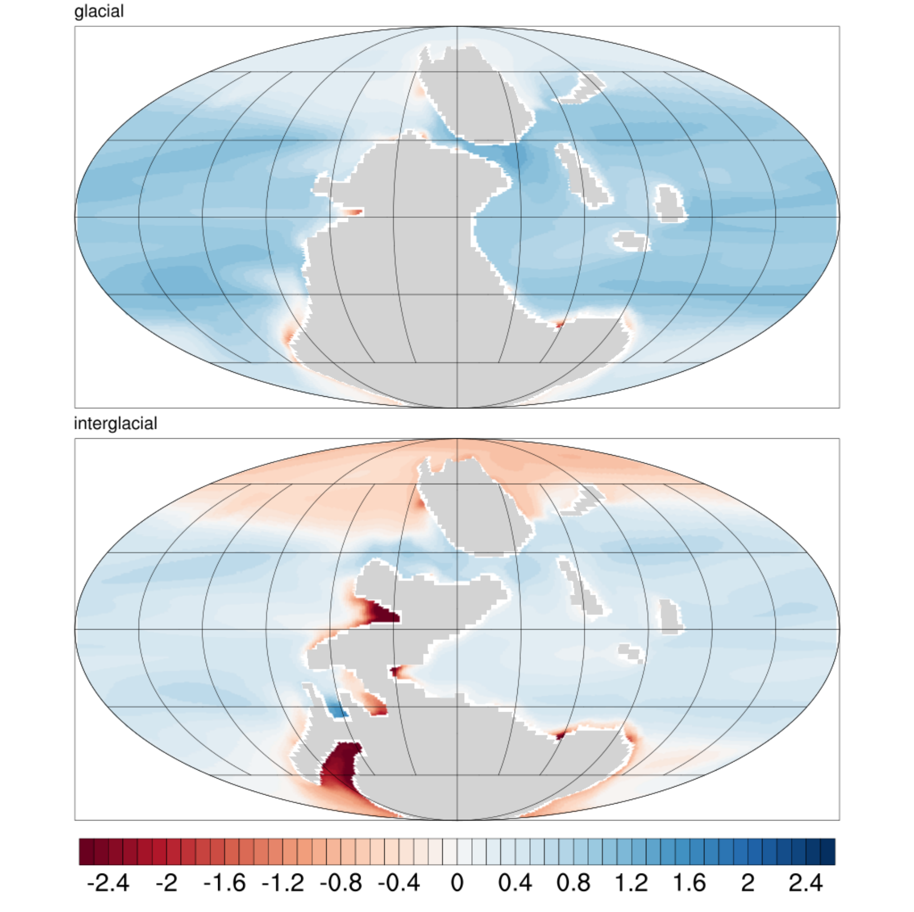
- Interglacial salinity in Midcontinent sea is low, particularly during interglacial high stand

Results: Mean annual SSS & precipitation



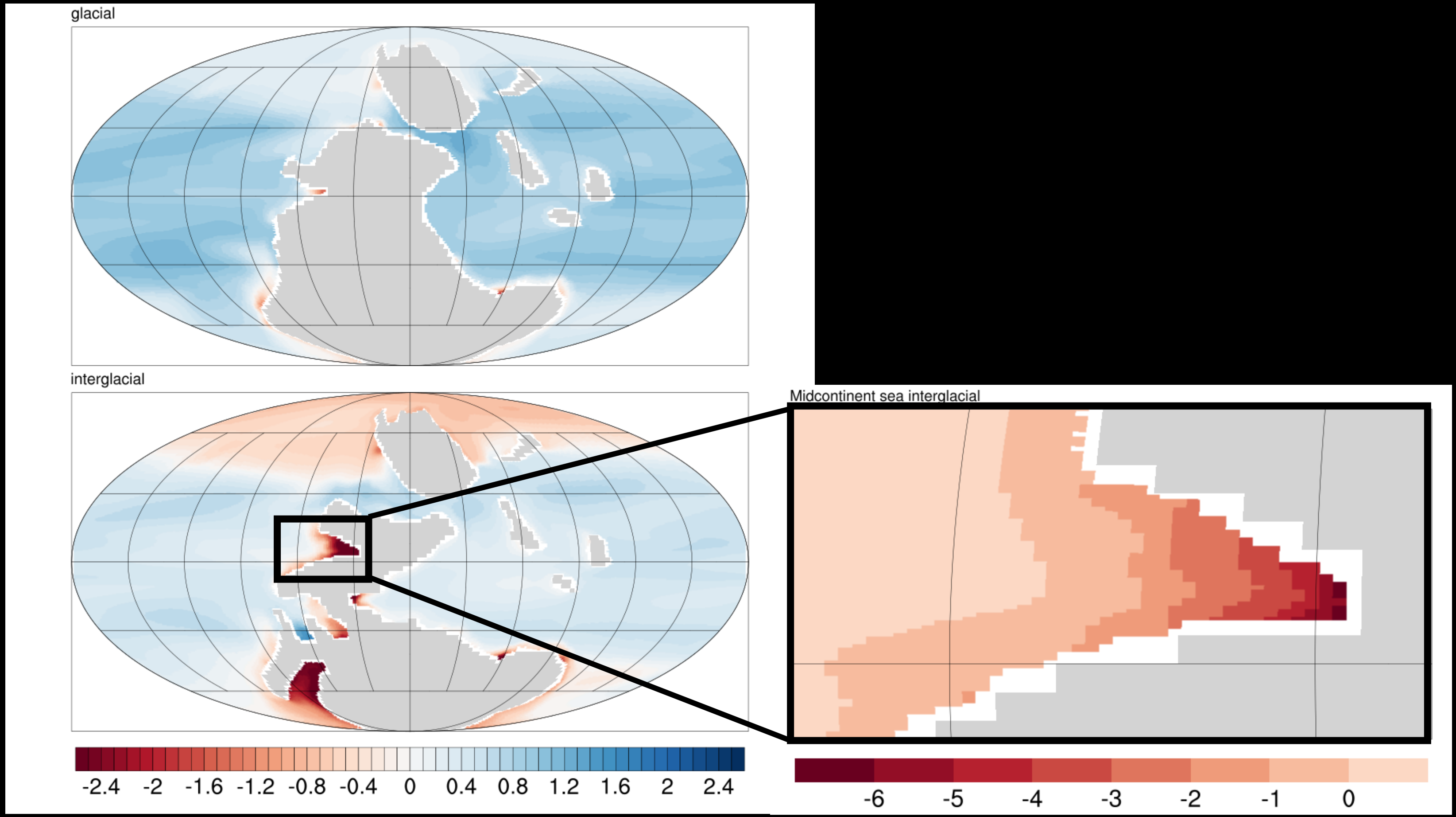
- Interglacial salinity in Midcontinent sea is low, particularly during interglacial high stand
- Depleted $\delta^{18}O$ of precipitation and runoff from Central Pangean Mountains into Midcontinent sea

Results: Mean annual seawater δ^{18}O (‰)



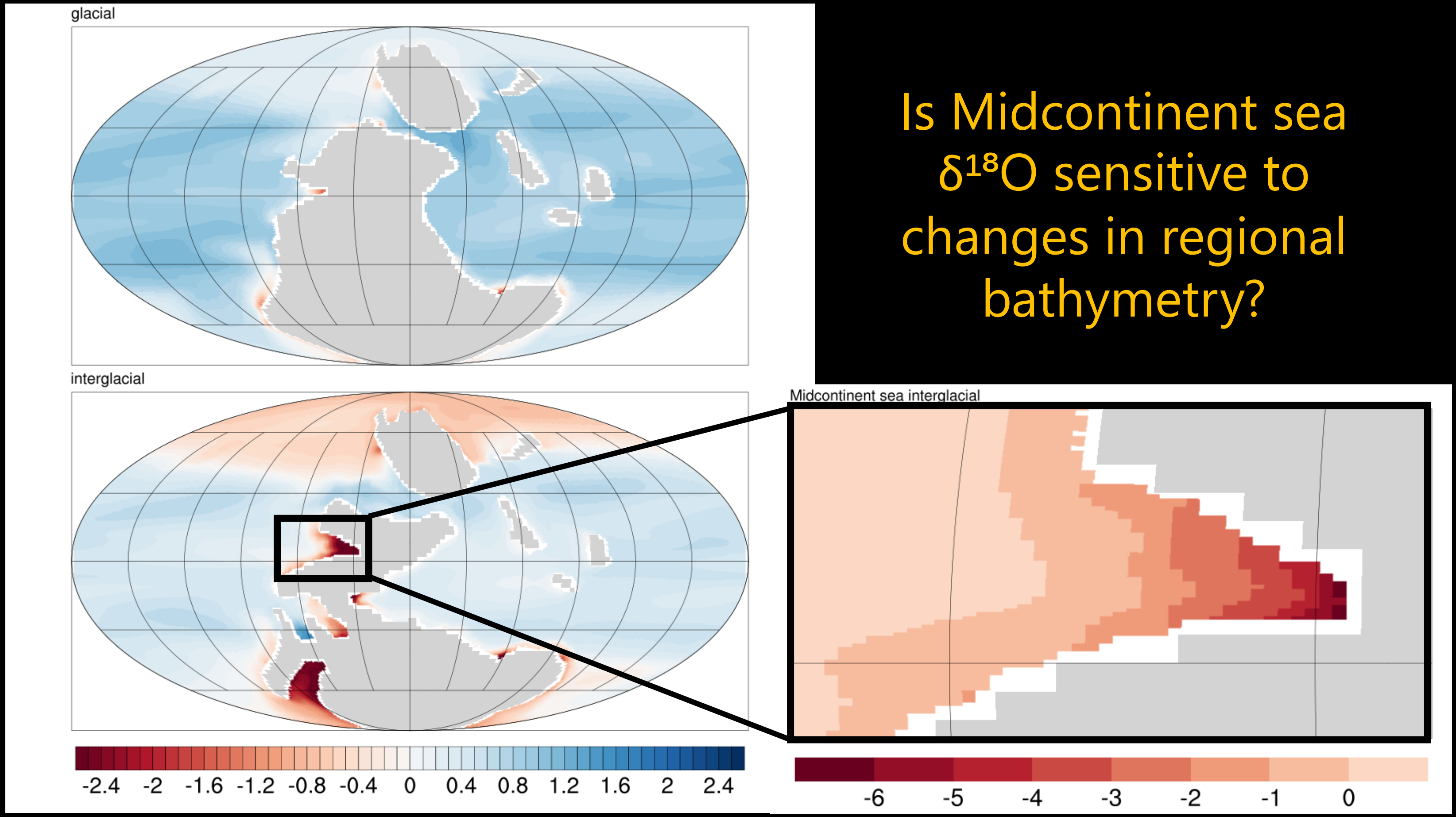
- Relatively more enriched δ^{18}Osw in glacial
- Gradient of decreasing δ^{18}Osw from equator to the poles

Results: Mean annual seawater $\delta^{18}O$ (‰)



- Relatively more enriched $\delta^{18}O_{sw}$ in glacial
- Gradient of decreasing $\delta^{18}O_{sw}$ from equator to the poles
- Interglacial $\delta^{18}O_{sw}$ gradient of >5‰ over Midcontinent sea from high riverine influx

Results: Mean annual seawater δ¹⁸O (‰)



Is Midcontinent sea $\delta^{18}O$ sensitive to changes in regional bathymetry?

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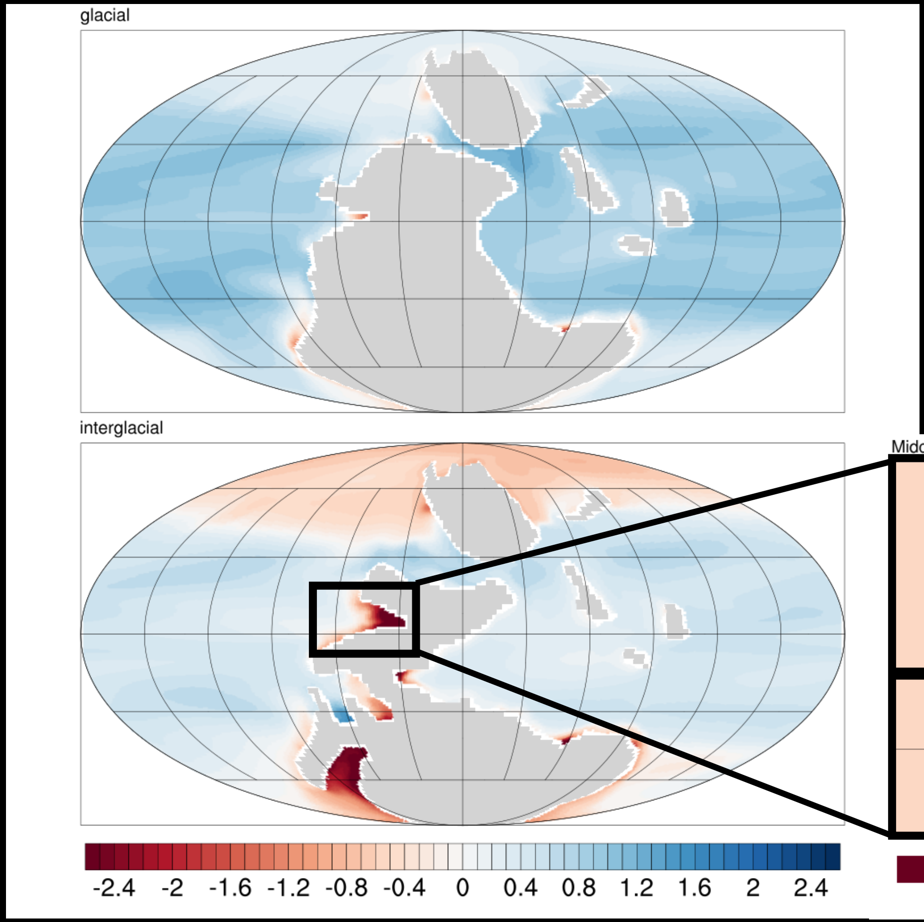

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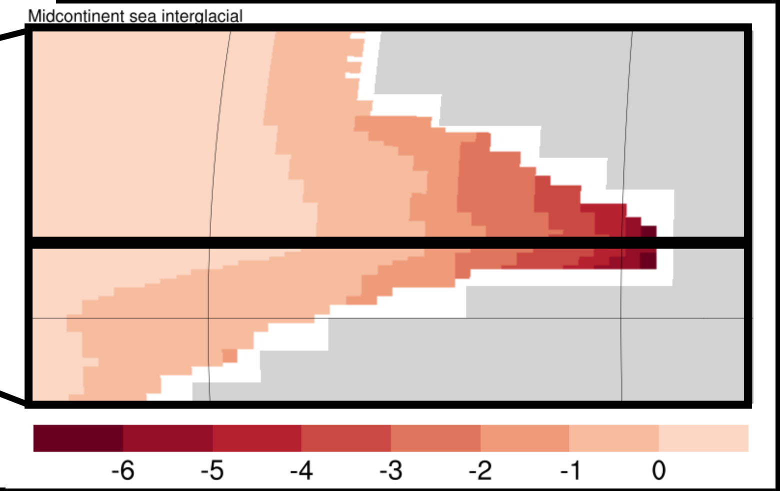

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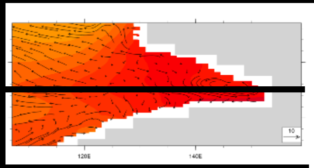
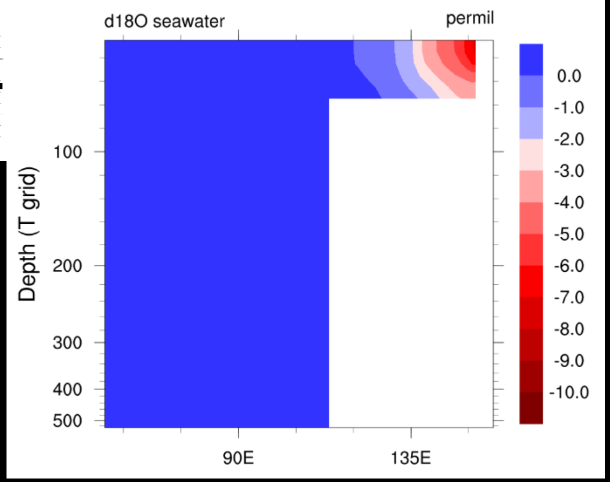
Results: Sensitivity of Midcontinent δ¹⁸O

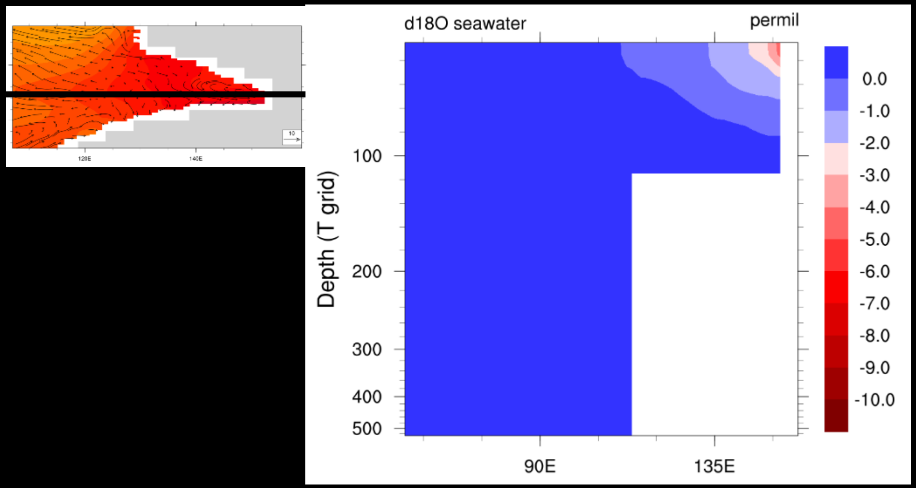
60 m depth





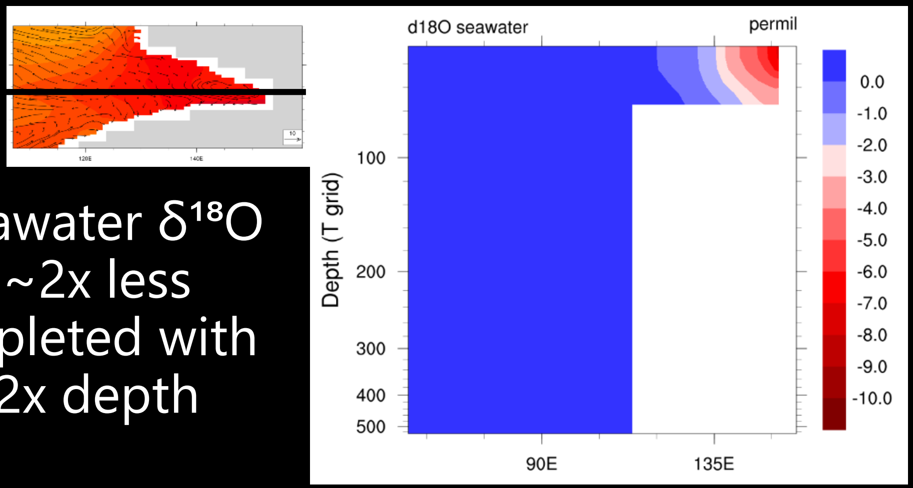
Results: Sensitivity of Midcontinent δ^{18}O

120 m depth



Seawater δ^{18}O ~2x less depleted with 2x depth

60 m depth



Results: Sensitivity of Midcontinent $\delta^{18}O$

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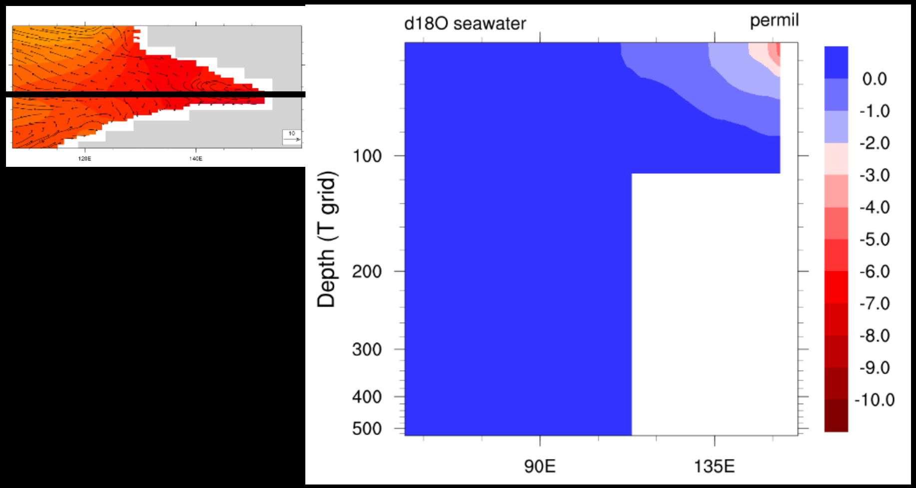

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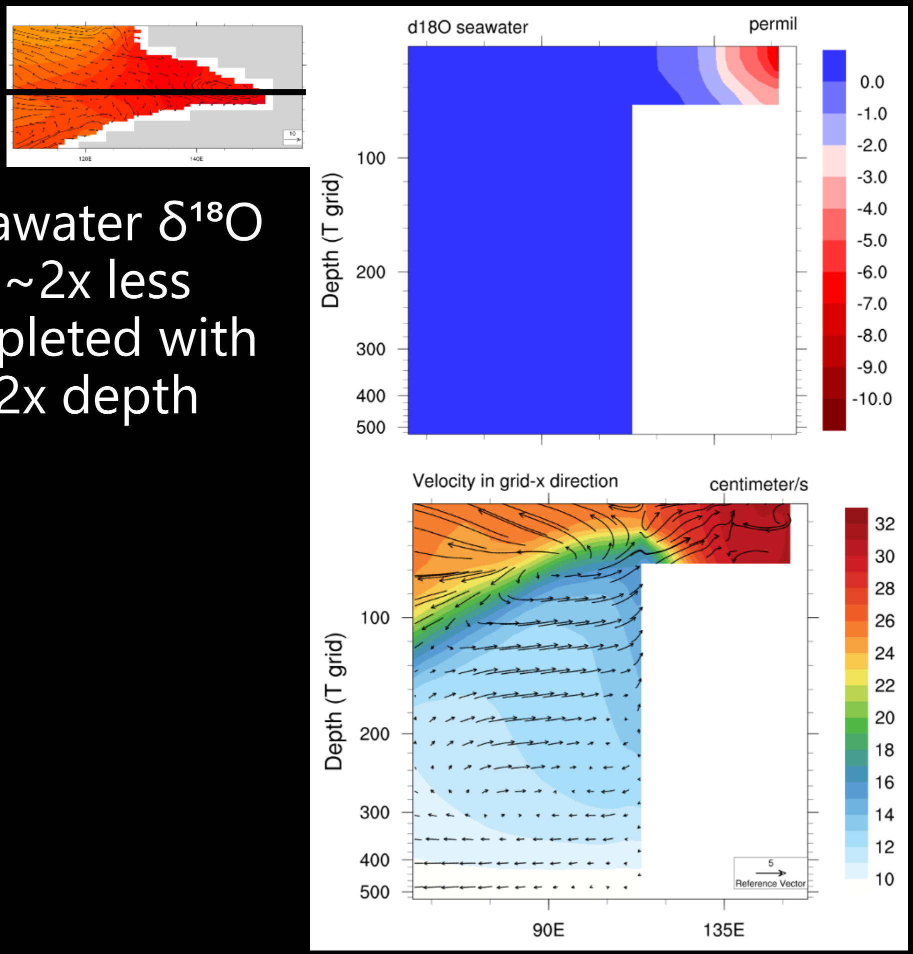

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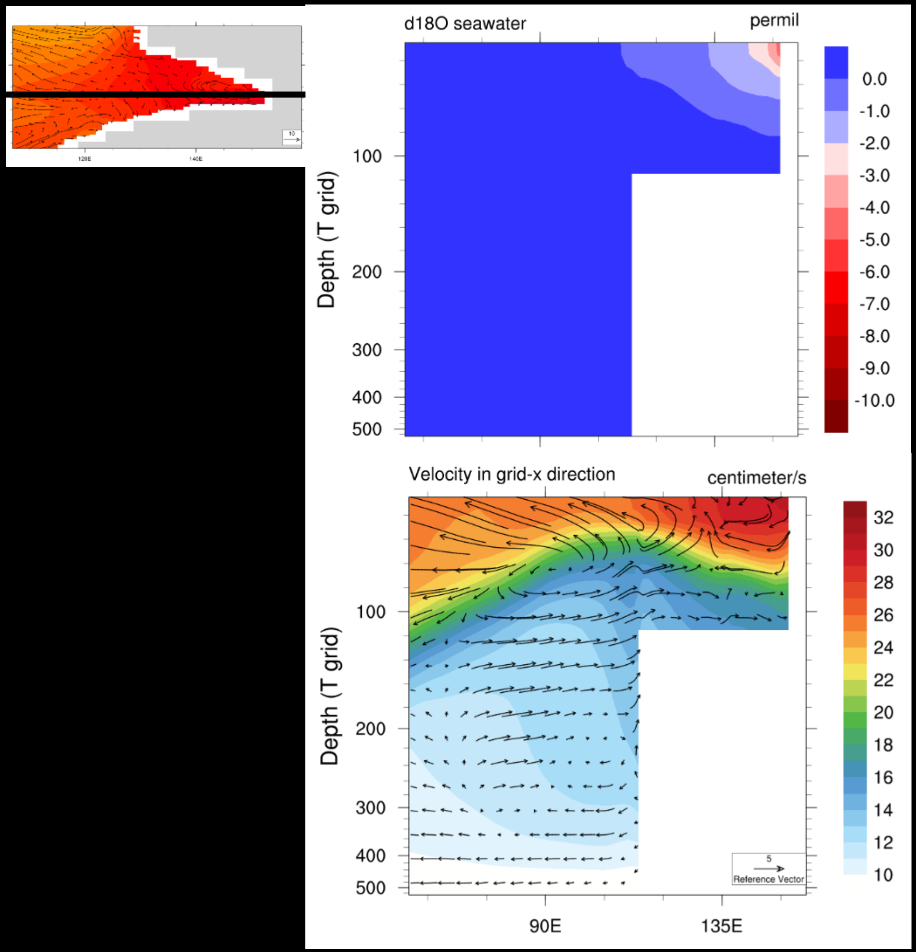

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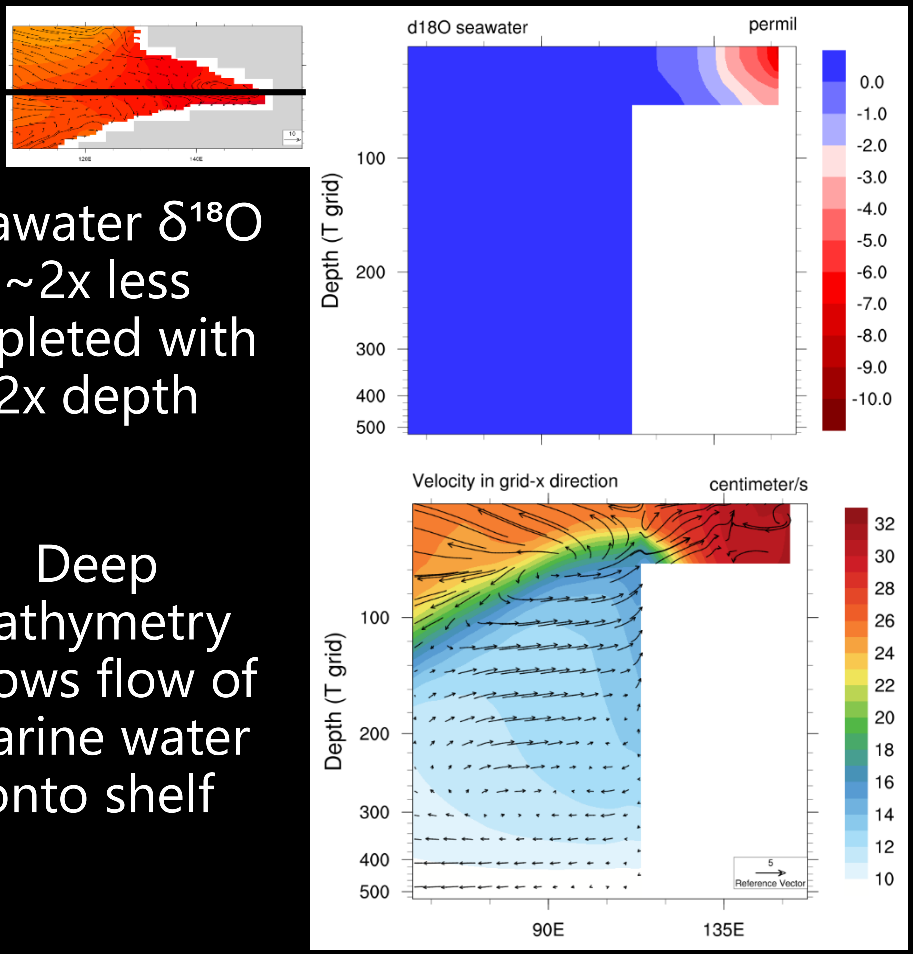
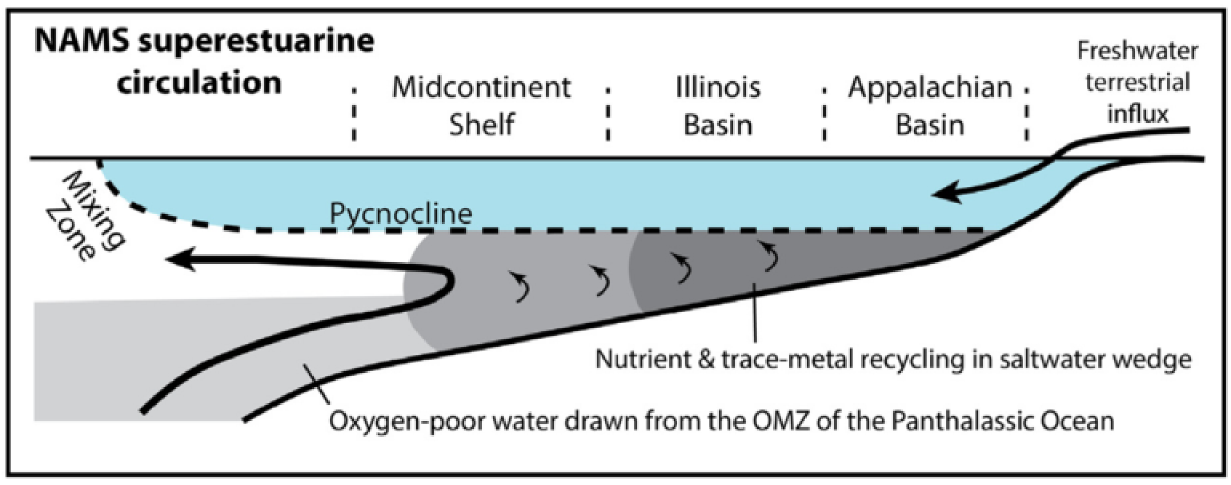


Seawater δ¹⁸O ~2x less depleted with 2x depth

Deep bathymetry allows flow of marine water onto shelf

Results: Sensitivity of Midcontinent $\delta^{18}O$

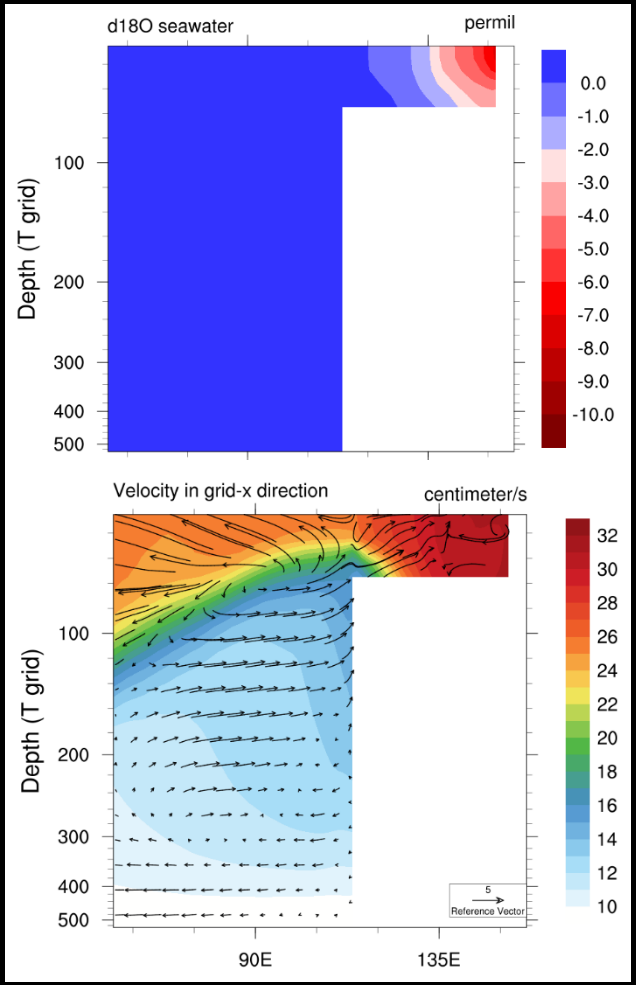
- North American Midcontinent Sea (NAMS) has a mean depth of 50 m (Algeo & Heckel, 2008)



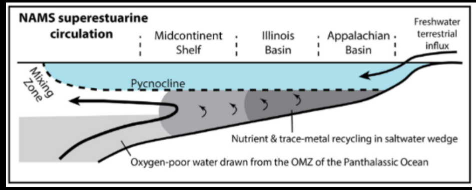
(Turner et al., 2018)

Results: Sensitivity of Midcontinent $\delta^{18}O$

Uniform 60 m

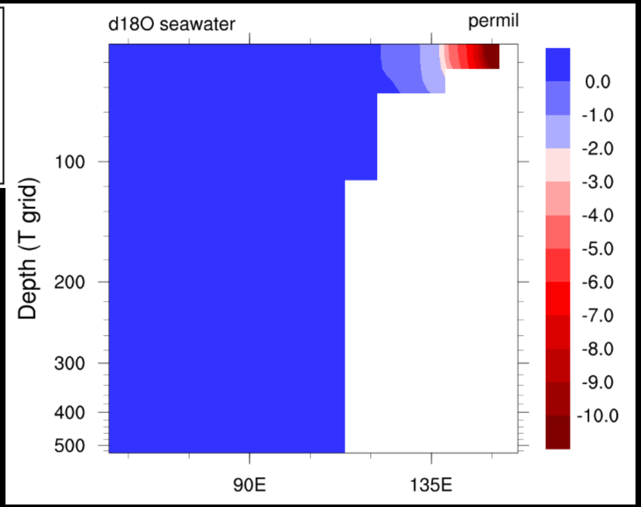


Results: Sensitivity of Midcontinent $\delta^{18}O$



Despite open coastline, shallow depth creates >10‰ gradient in seawater $\delta^{18}O$

Mean 50 m



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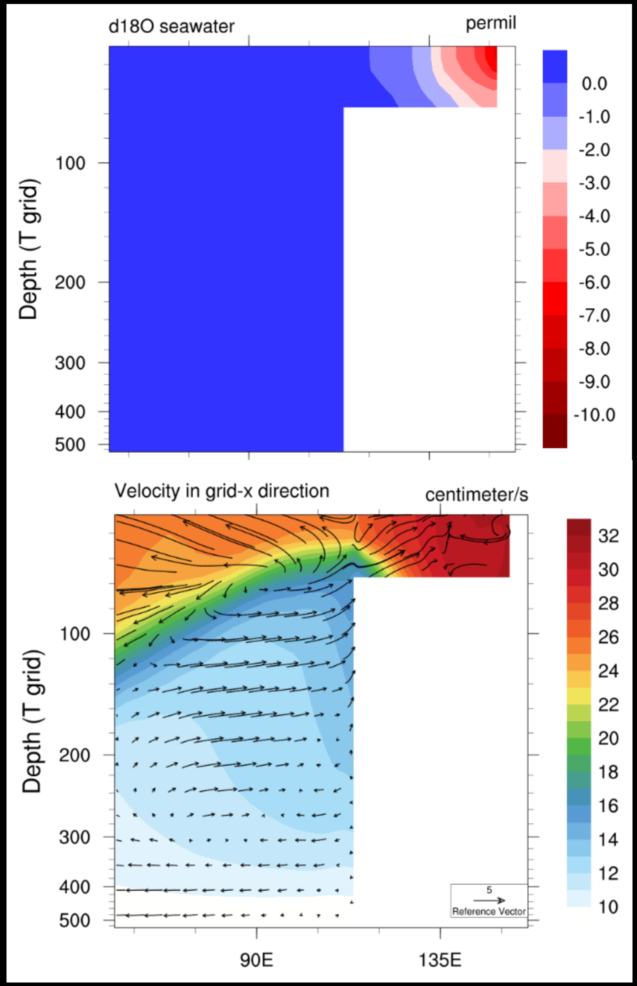
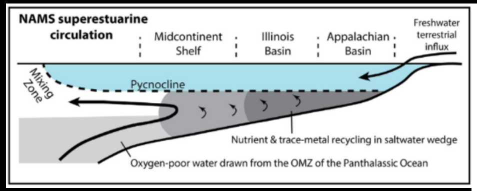


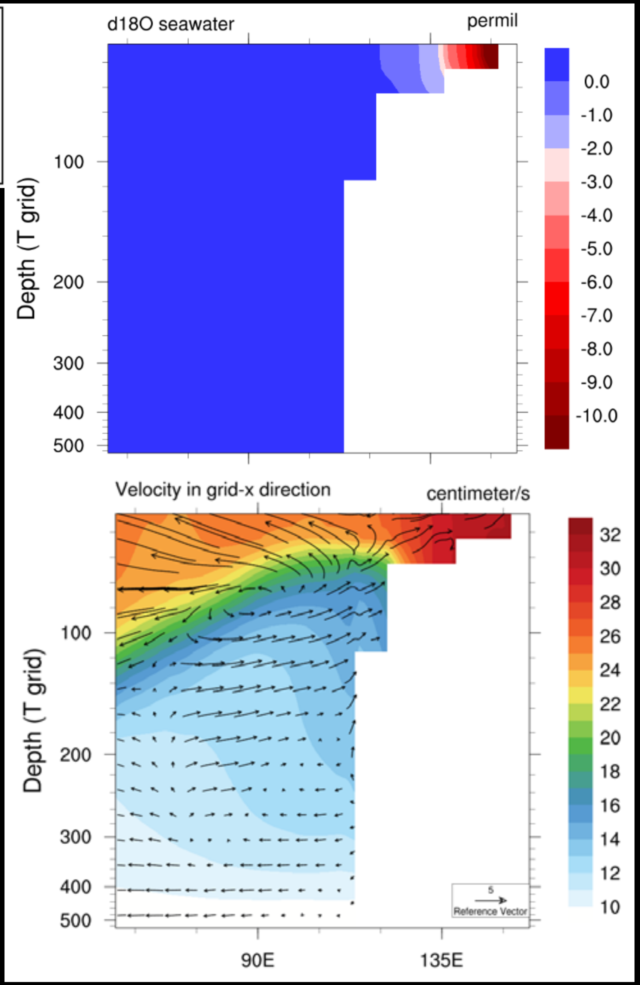
Results: Sensitivity of Midcontinent δ18O



Despite open coastline, shallow depth creates >10‰ gradient in seawater δ18O

Mean depth >50 m needed for flow of marine deepwater into eastern sea

Mean 50 m



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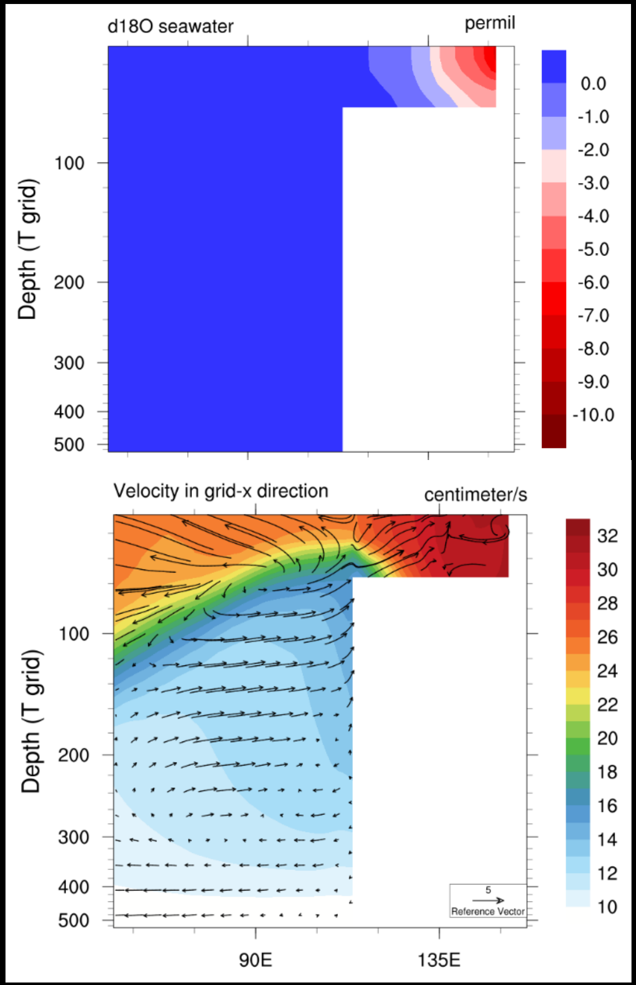
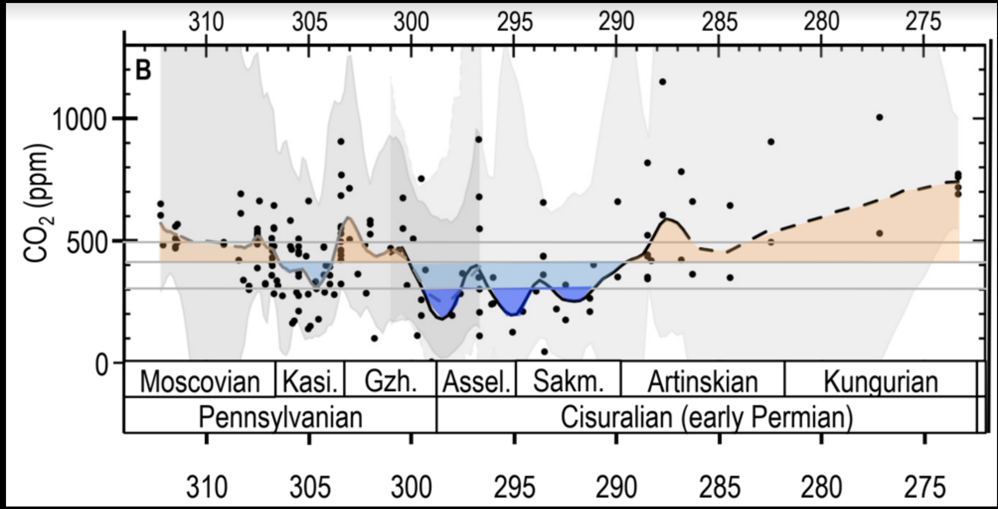


Results: Data-model comparison

(Isabel Montañez, personal comm.)

- Compiled proxy data from an interglacial (304 – 302 Ma) interval
- Calculated paleotemperatures using simulated and assumed δ¹⁸Osw



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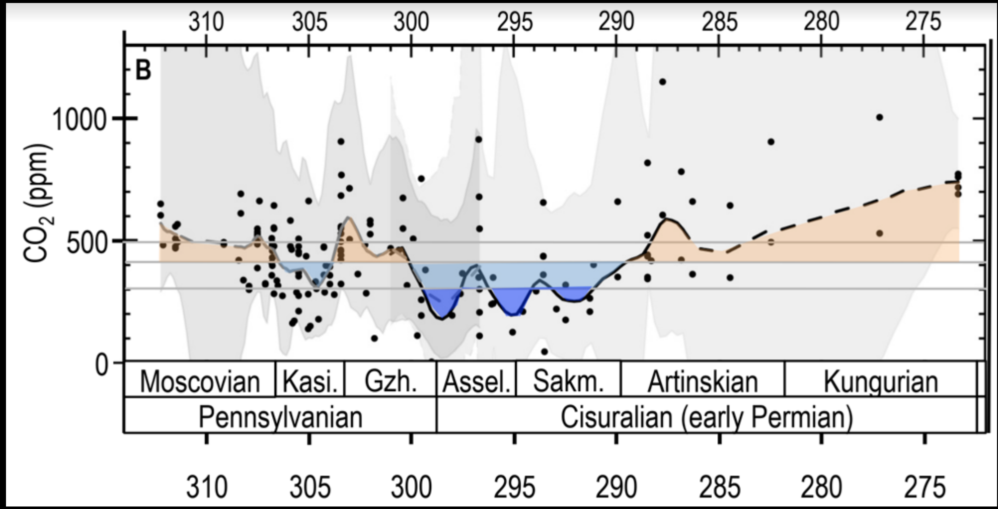

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  - Brachiopod carbonate δ^{18}O

$$T(°C) = 15.7 - 4.36(\delta^{18}O_{calcite} - \delta^{18}O_{sw}) + 0.12(\delta^{18}O_{calcite} - \delta^{18}O_{sw})^2$$

Hays & Grossman (1991)

  - Conodonts phosphate δ^{18}O

$$T(°C) = 118.7 - 4.22\left(\delta^{18}O_{phosphate} + (22.6 - \delta^{18}O_{NBS120c}) - \delta^{18}O_{sw}\right)$$

Puceat et al. (2010)

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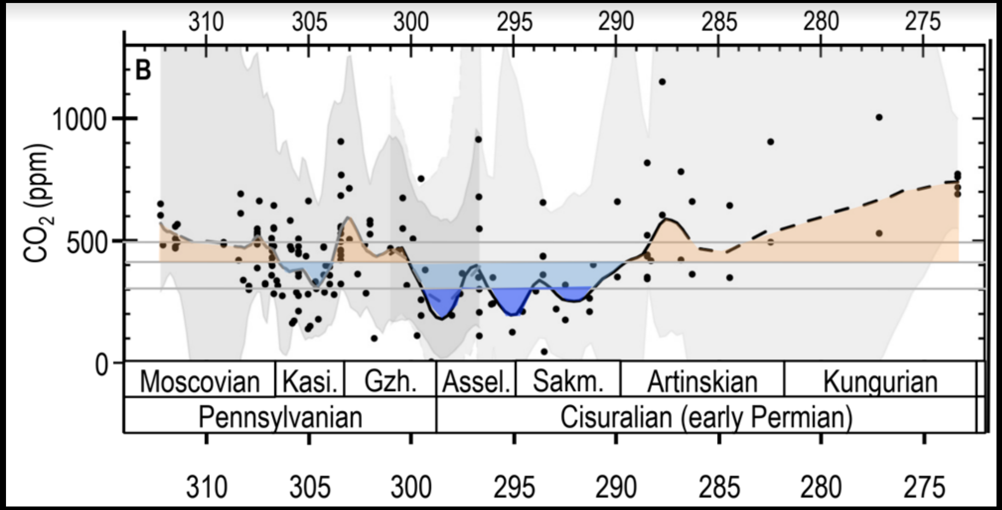

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Usually assumed to be ~0‰

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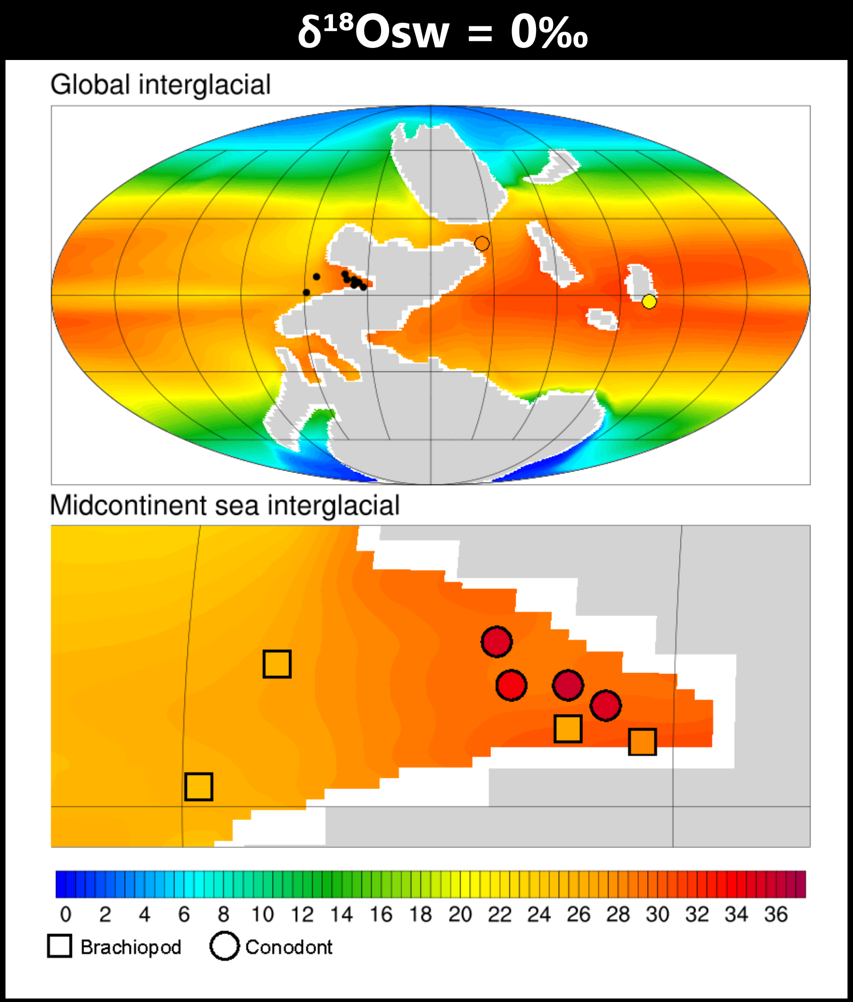
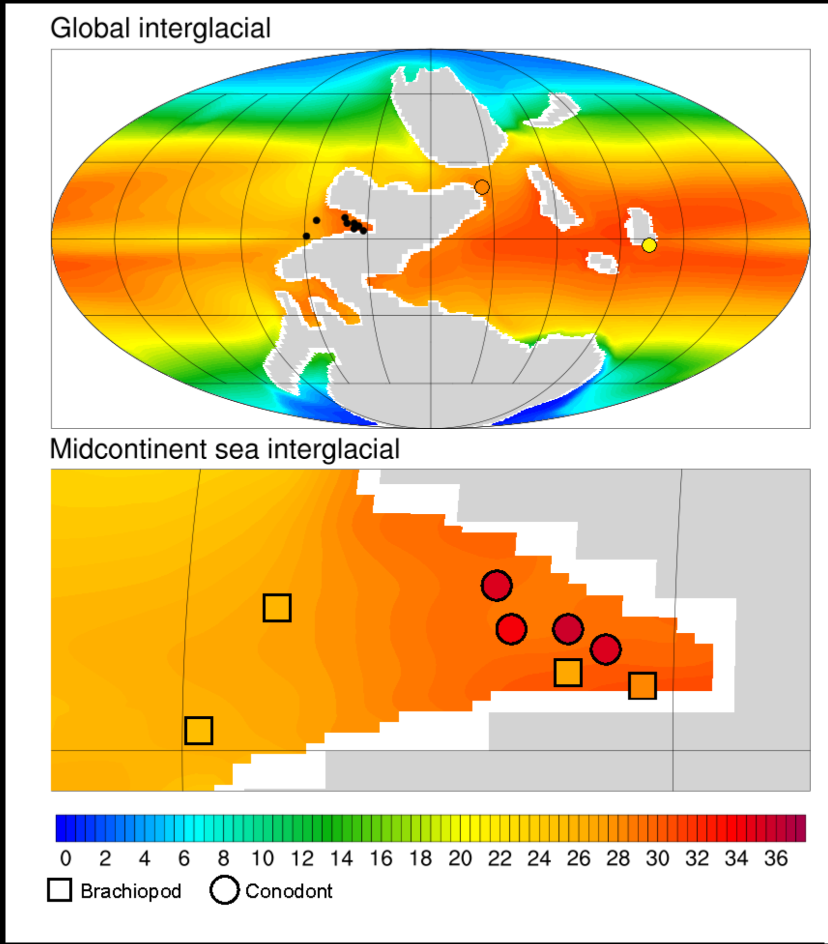


Mean annual SSTs and proxy-derived temperatures (⁰C)

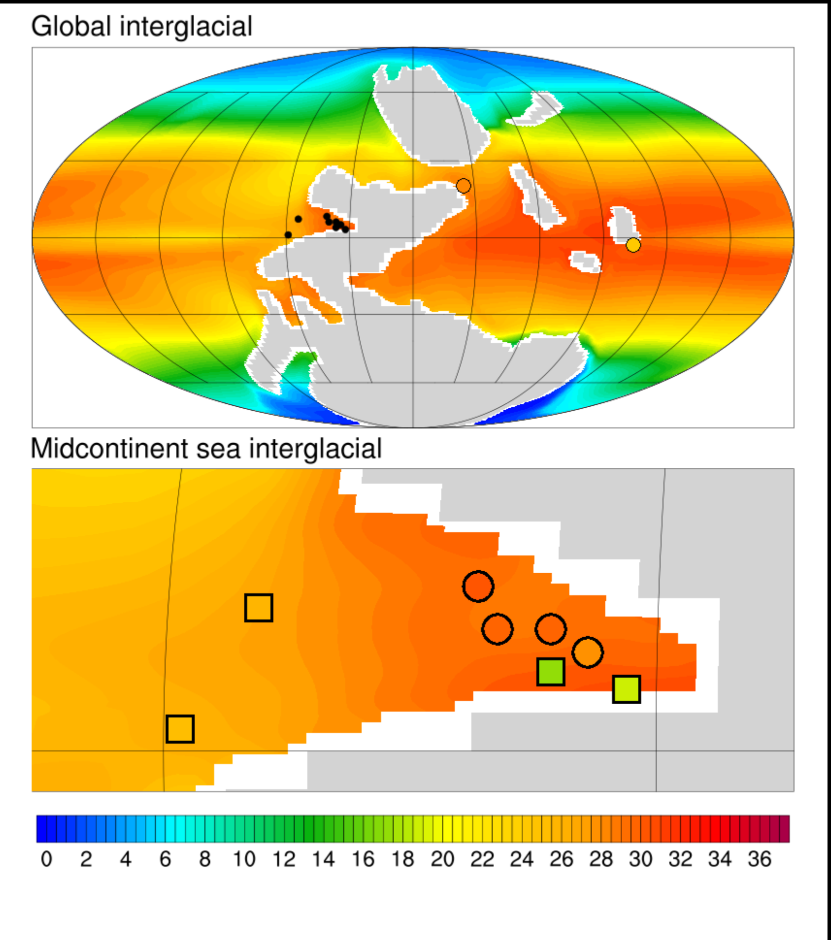
Proxy-derived temperatures are too high compared to simulated SSTs (Joachimski & Lambert, 2015; Roark et al., 2017)

Results: Data-model comparison

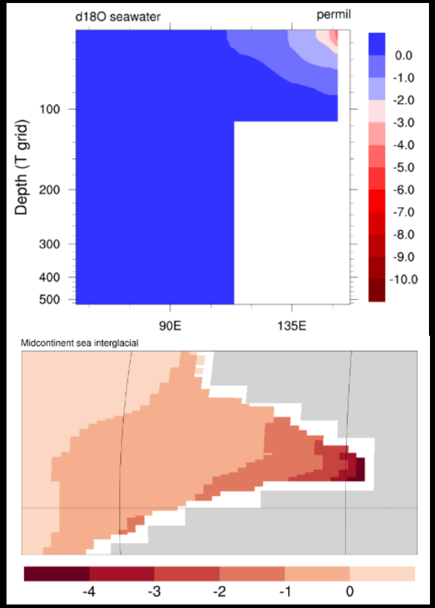
$\delta^{18}O_{sw}$ = 0‰



Model $\delta^{18}O_{sw}$



Conservative $\delta^{18}O_{sw}$



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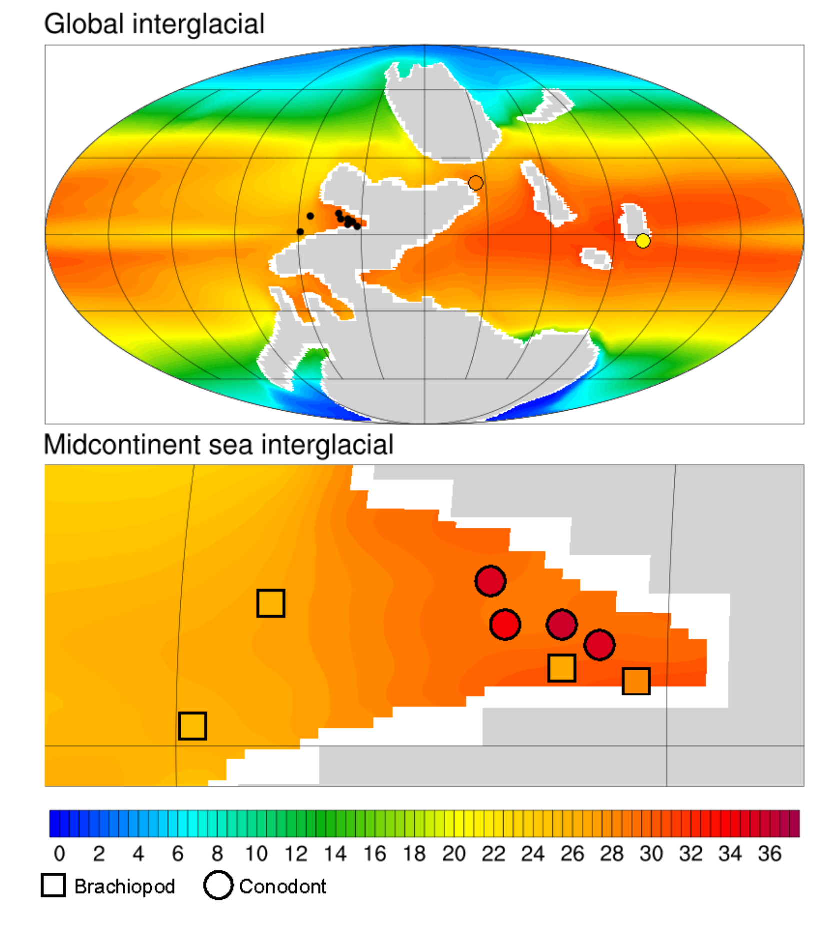

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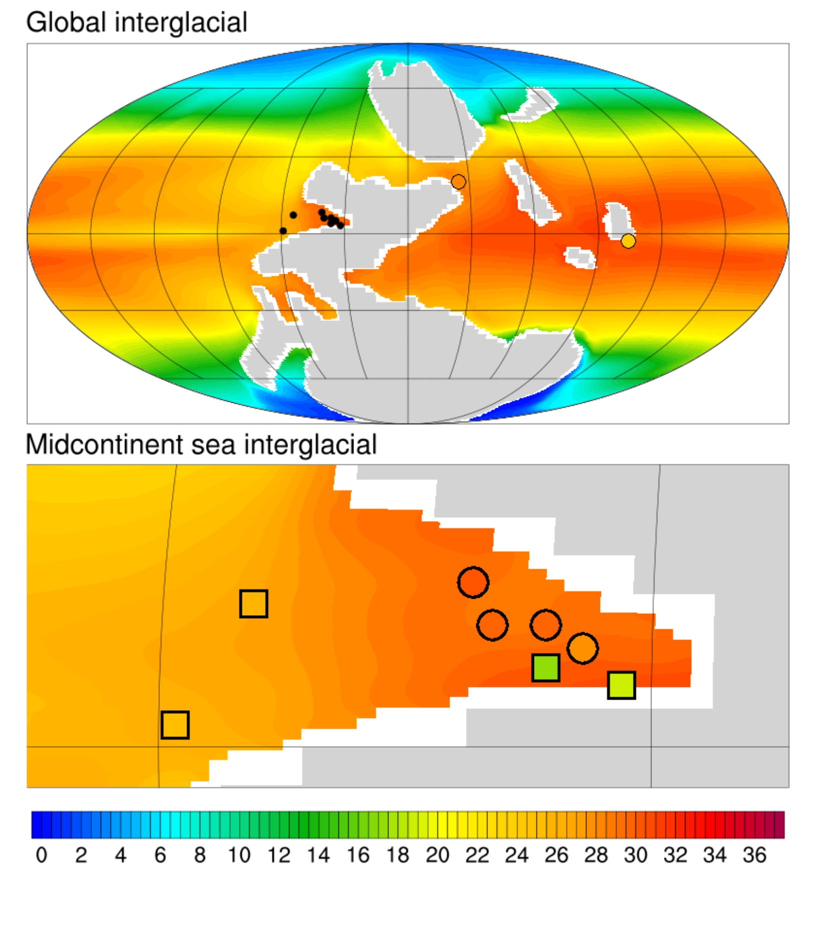
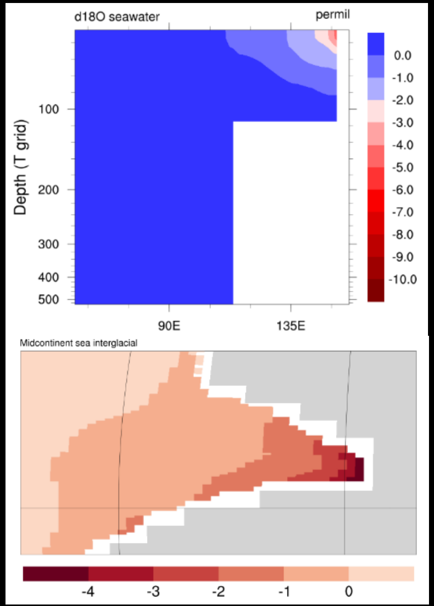


Proxy-derived temperatures more closely resemble simulated SSTs

Conservative $\delta^{18}Osw$



Conclusions

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  - Magnitude of seawater $\delta^{18}O$ depletion is dependent on regional bathymetry

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  - Magnitude of seawater $\delta^{18}O$ depletion is dependent on regional bathymetry
- Knowledge of the regional hydrologic processes that influence epicontinental seas may improve $\delta^{18}O$ paleotemperature estimates in deep time
  - Such processes can be constrained with isotope-enabled Earth system models (i.e. iCESM)

Thank you!