Ocean deoxygenation linked to abrupt global warming during the Earth's penultimate icehouse

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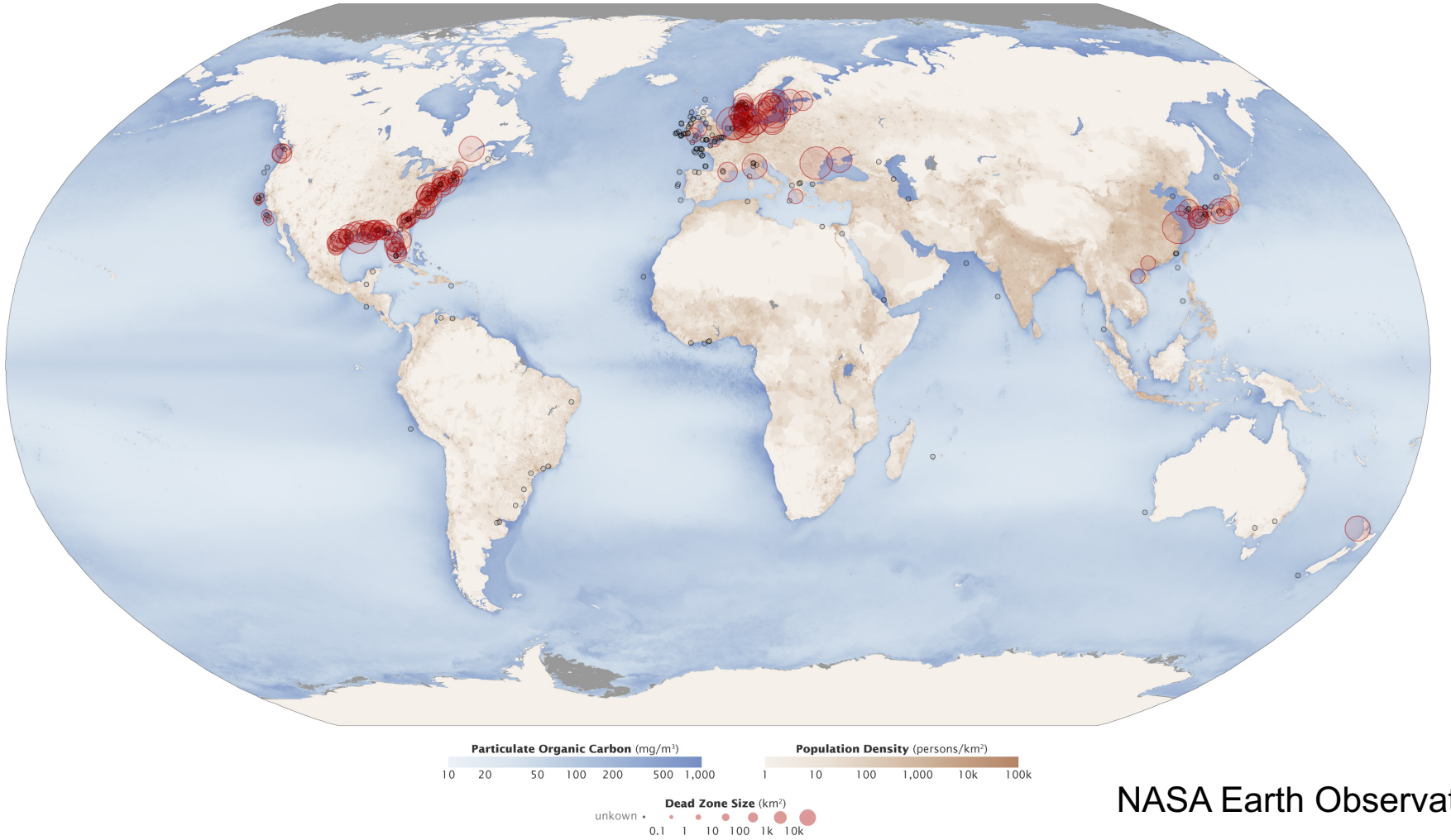
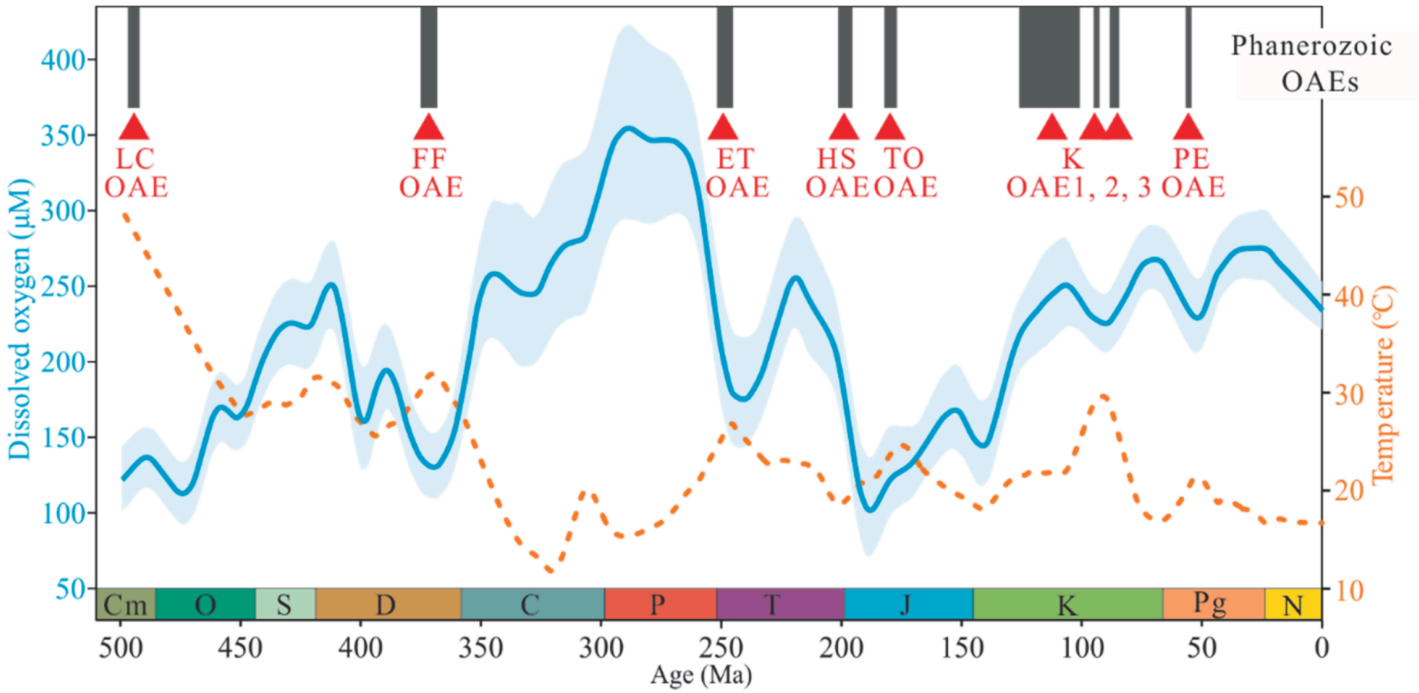
Ocean deoxygenation in a warming world



NASA Earth Observatory

Piecing together past Ocean Anoxic Events (OAEs)

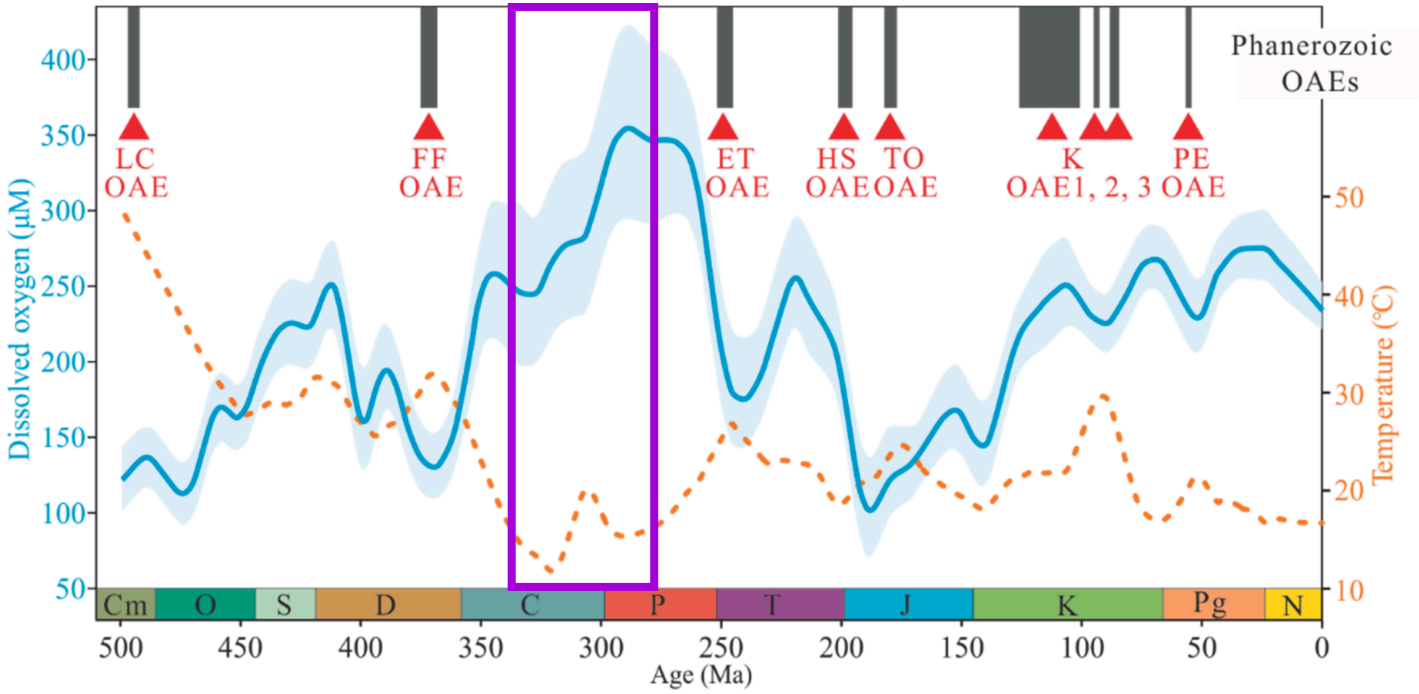
- Ocean deoxygenation is typically associated with warming, sea level rise, and even mass extinctions



Song et al. (2019), *Journal of Earth Science*

Piecing together past Ocean Anoxic Events (OAEs)

- Late Paleozoic Ice Age (**LPIA**, ~340-285 Mya) experienced CO_2 levels comparable to the Cenozoic glacial state



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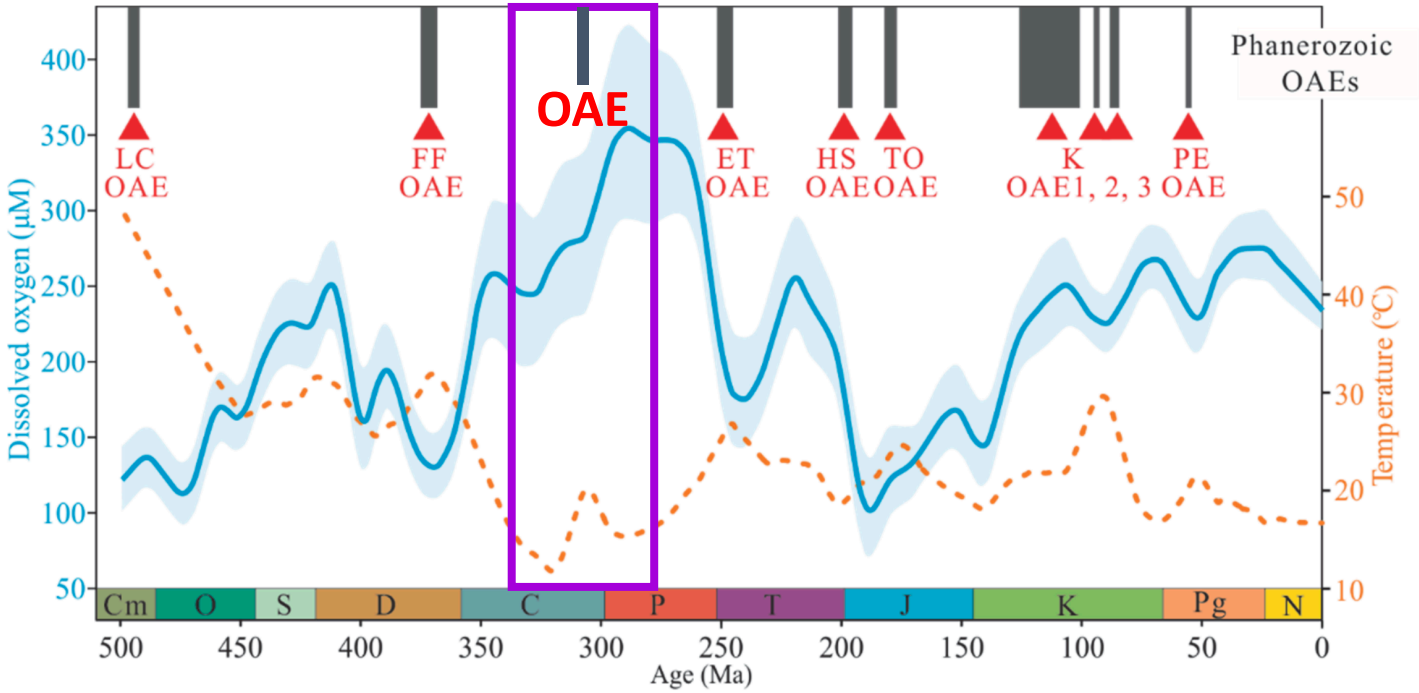
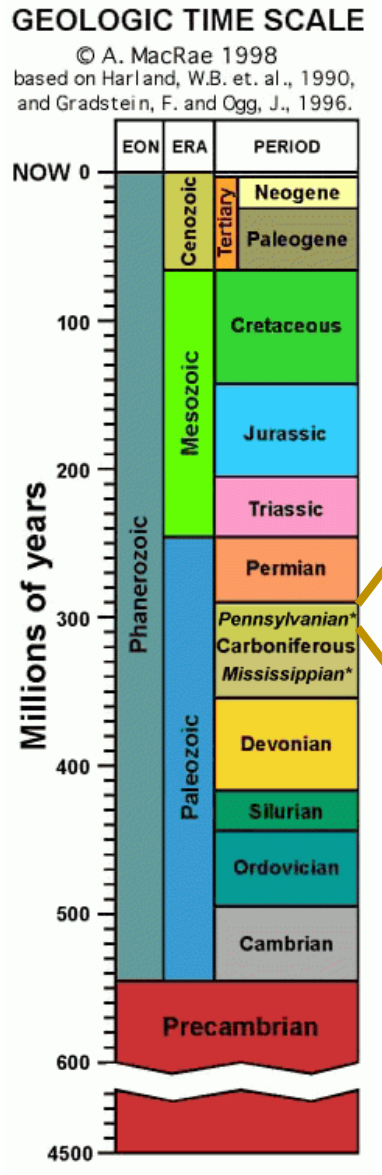
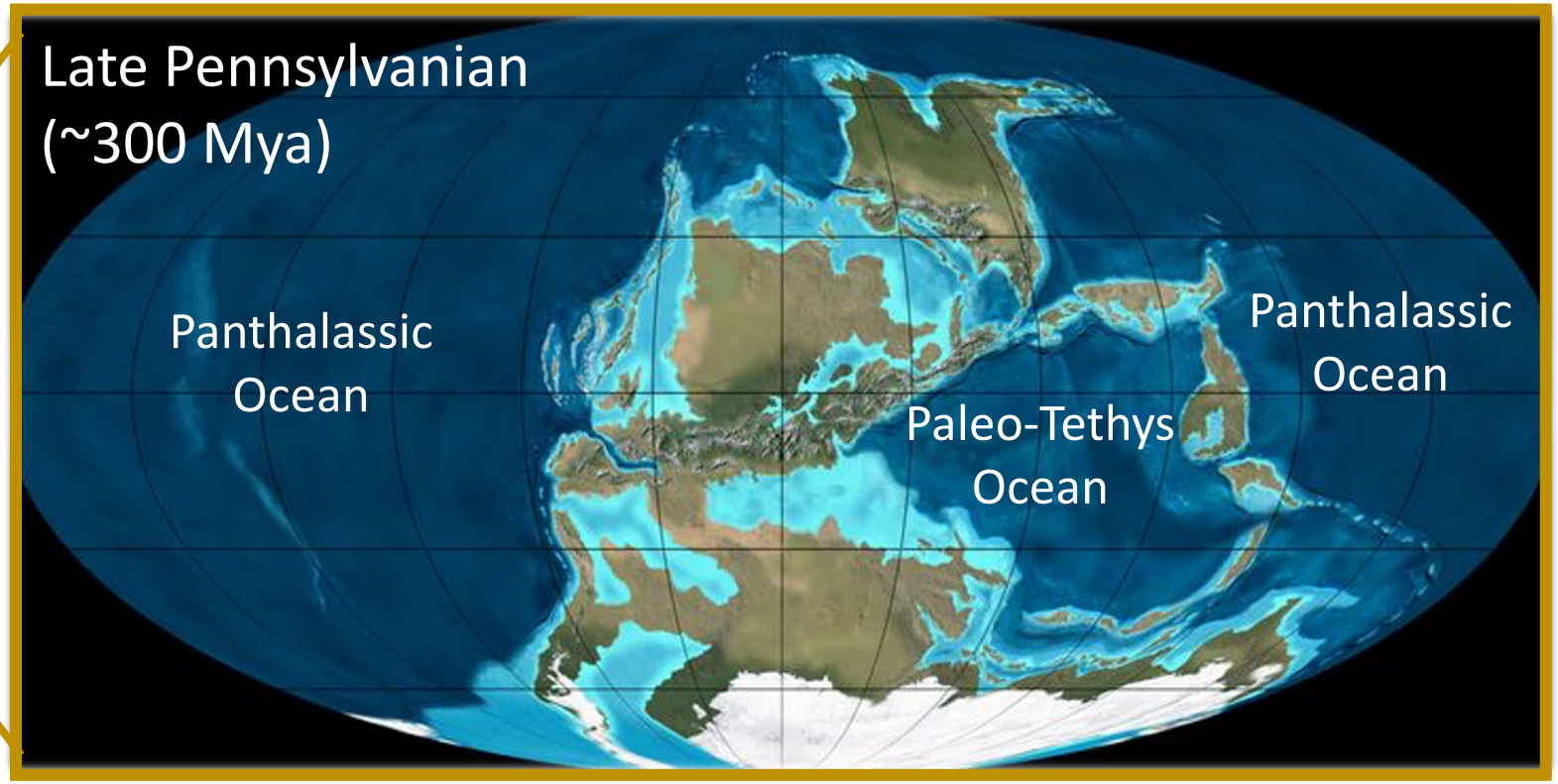


Modified from Song et al. (2019), *Journal of Earth Science*

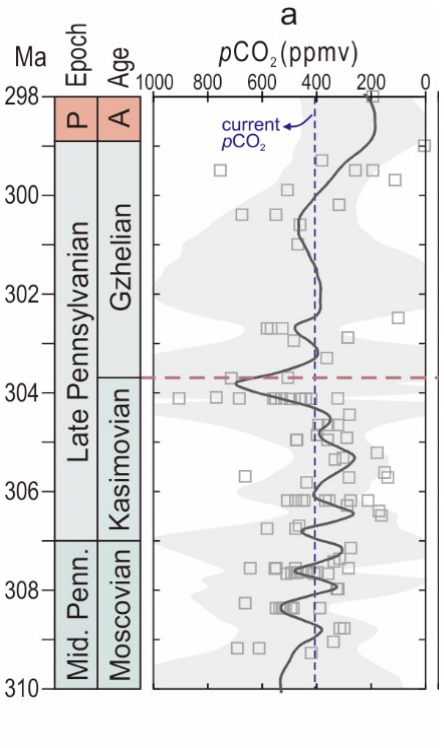
Earth's penultimate icehouse





Kasimovian–Gzhelian Boundary (**KGB**; ~304 Mya)

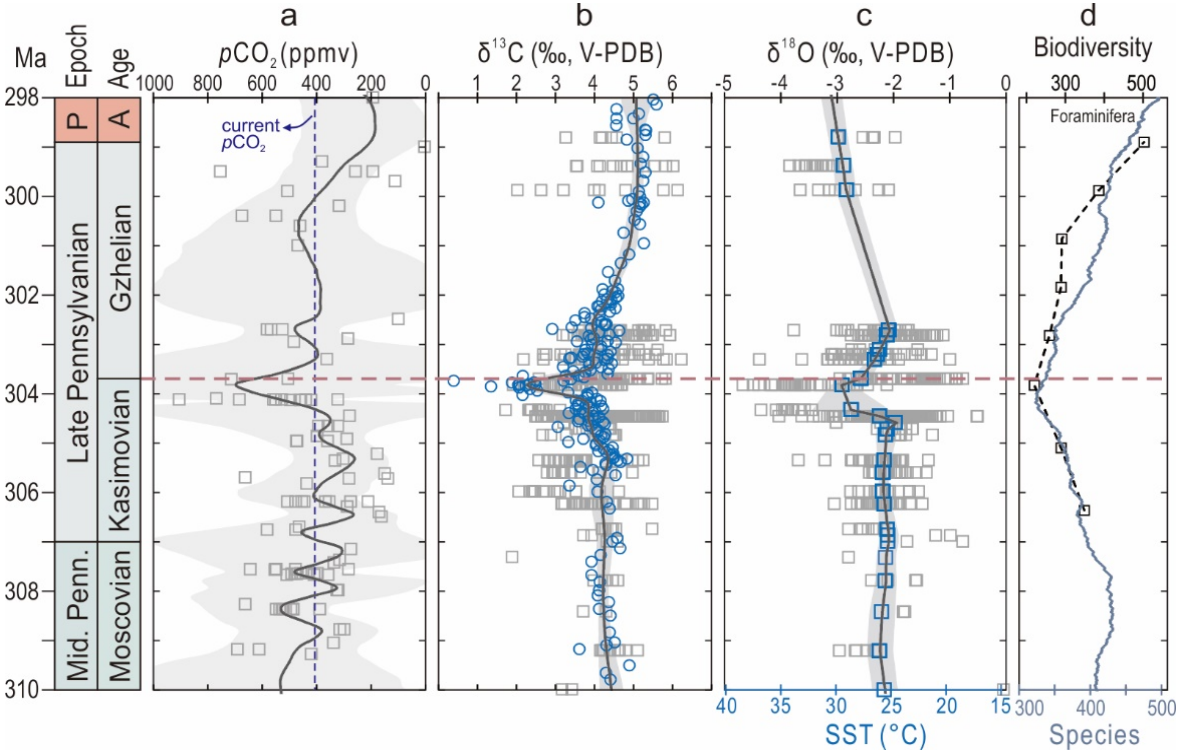
- Abrupt rise in atmospheric CO_2 from ~350 to 700 ppm over 300 kyr before the KGB



Modified from Richey et al. (2020), *Climate of the Past*

Kasimovian–Gzhelian Boundary (**KGB**; ~304 Mya)

- Abrupt rise in atmospheric CO_2 from ~350 to 700 ppm over 300 kyr before the KGB
- Coincides with temperature increase, sea level rise, and loss of marine biodiversity



Chen et al. (2021), *in revision*

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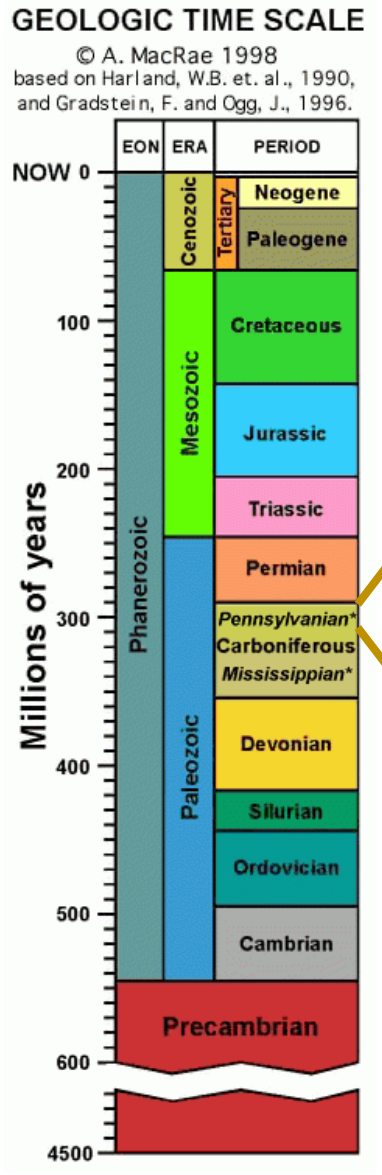
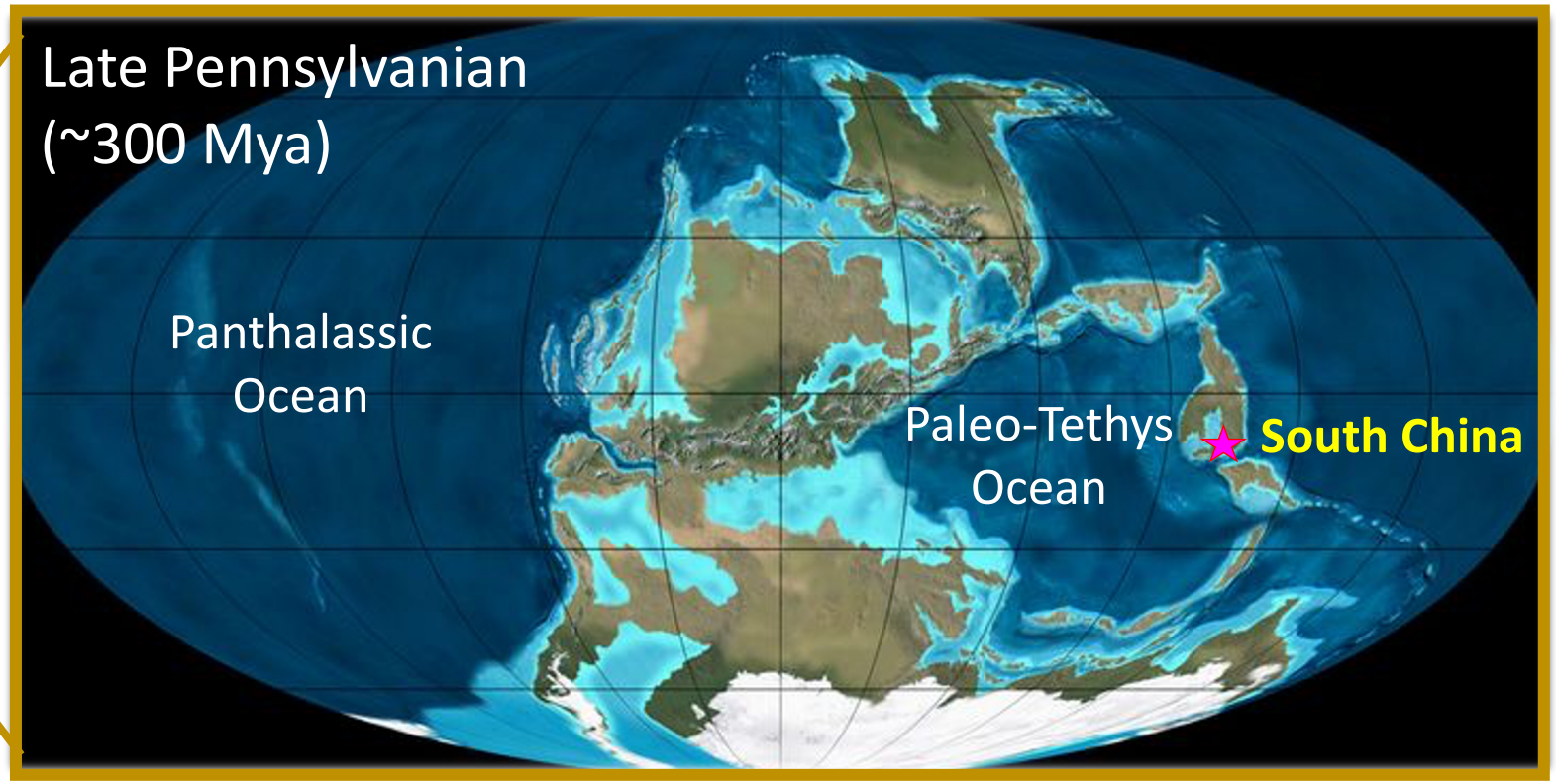
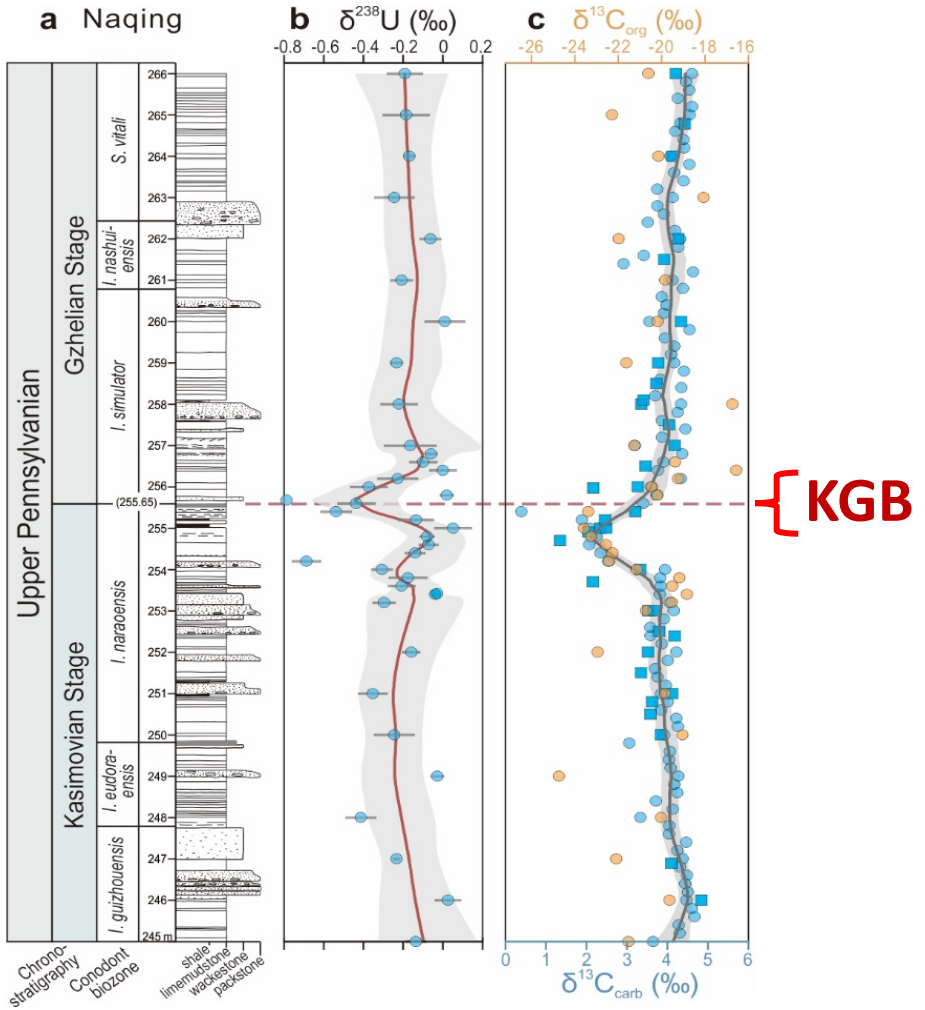




Warming coupled with marine anoxia at KGB

- Paired U and C records support a major carbon cycle perturbation coupled with ocean deoxygenation



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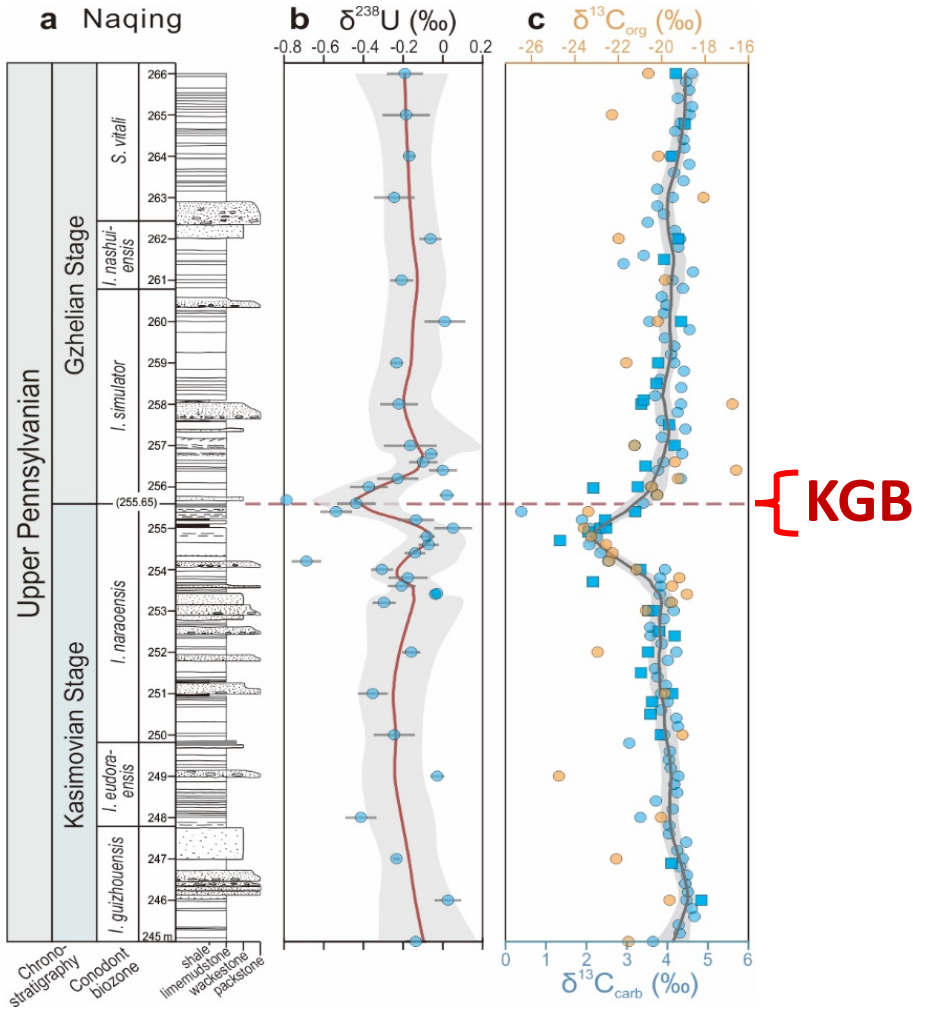
Warming coupled with marine anoxia at KGB

- Paired U and C records support a major carbon cycle perturbation coupled with ocean deoxygenation
- Carbon cycle (LOSCAR) and U mass balance modeling supports a 9000 Gt injection of organic matter-derived carbon over ~300 kyr, and a ~24% increase in the extent of anoxic seafloor area

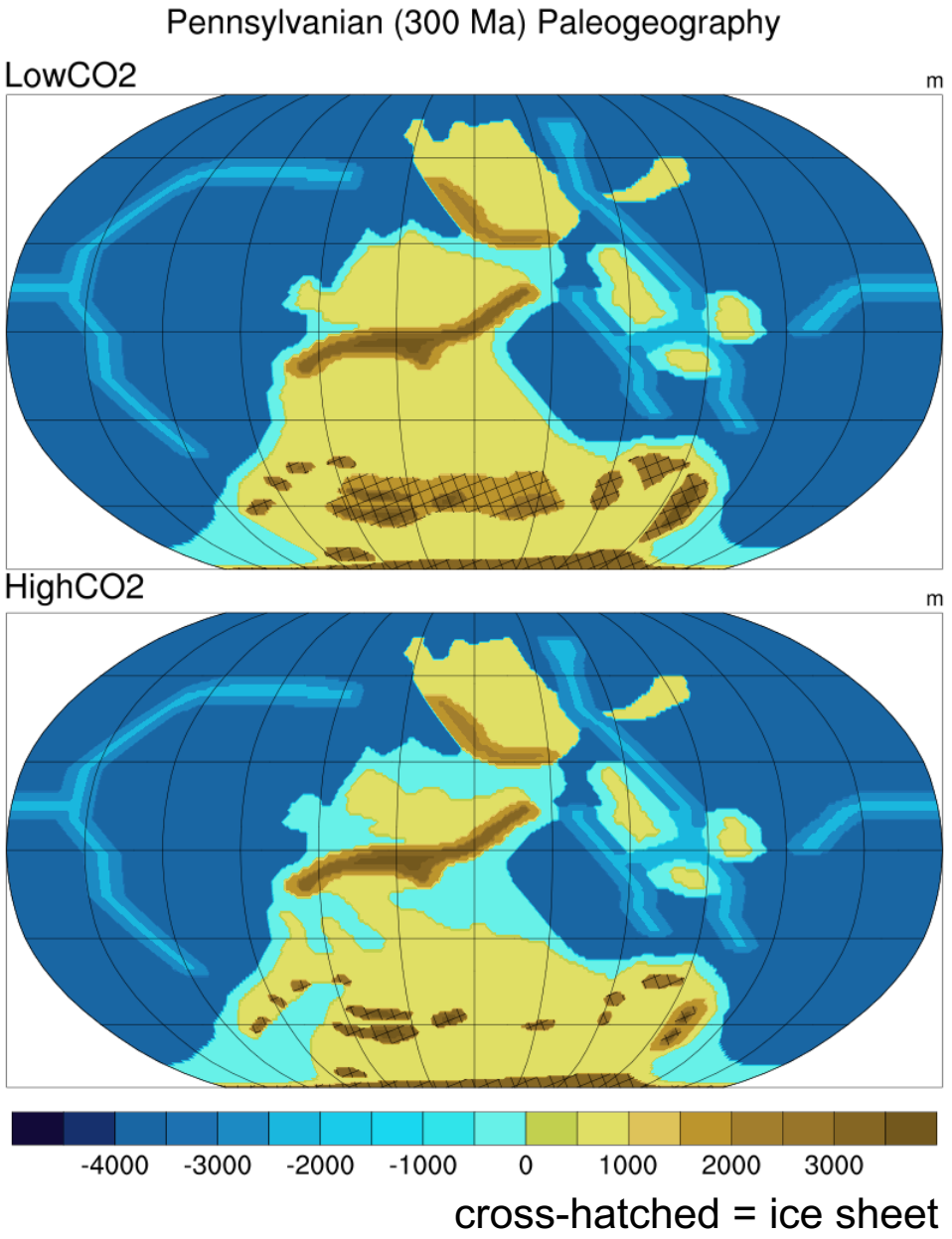


Modified from Chen et al. (2021), *in revision*

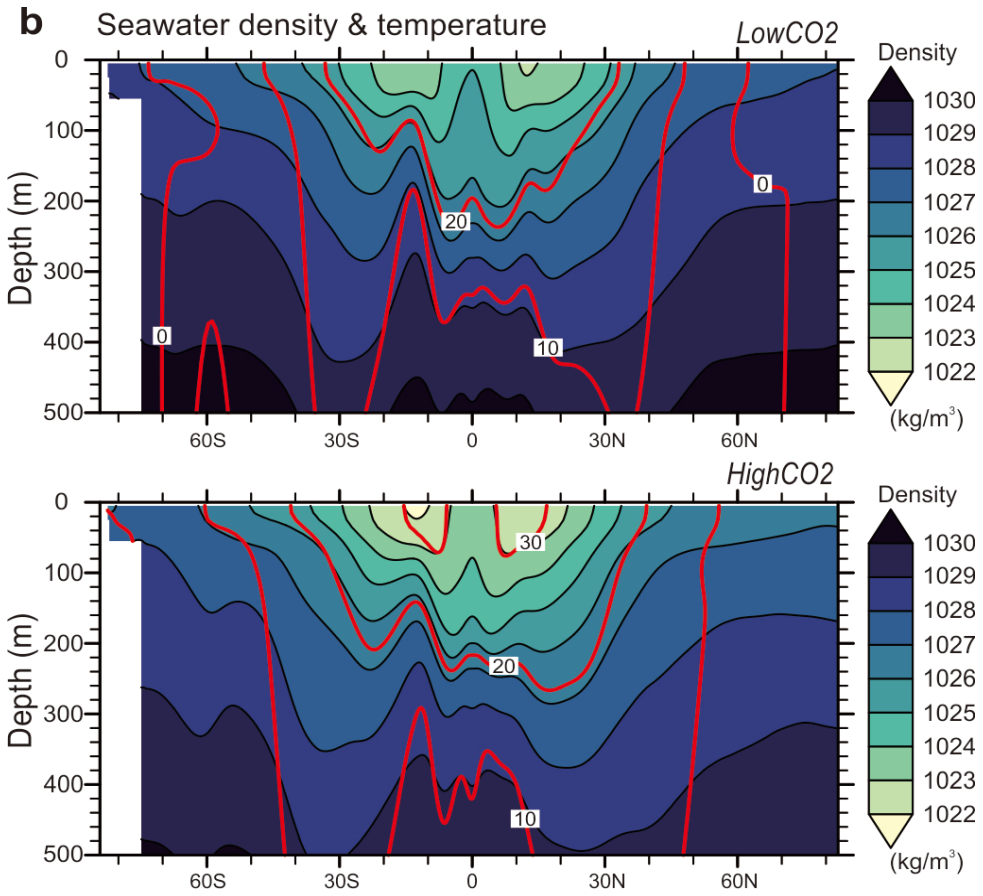
Fully-coupled Community Earth System Model 1.2

Cases	*LowCO2*	*HighCO2*
Ocean resolution	~1 degree	
Paleogeography	Late Pennsylvanian ~300 Ma (Domeier & Torsvik, 2014)	
Runtime	~2500 years	
Solar luminosity	97.5% of modern	
[CO_2]	280 ppm	560 ppm

Climate simulations used to propose a physical mechanism for ocean deoxygenation at the KGB



Enhanced upper ocean stratification with warming



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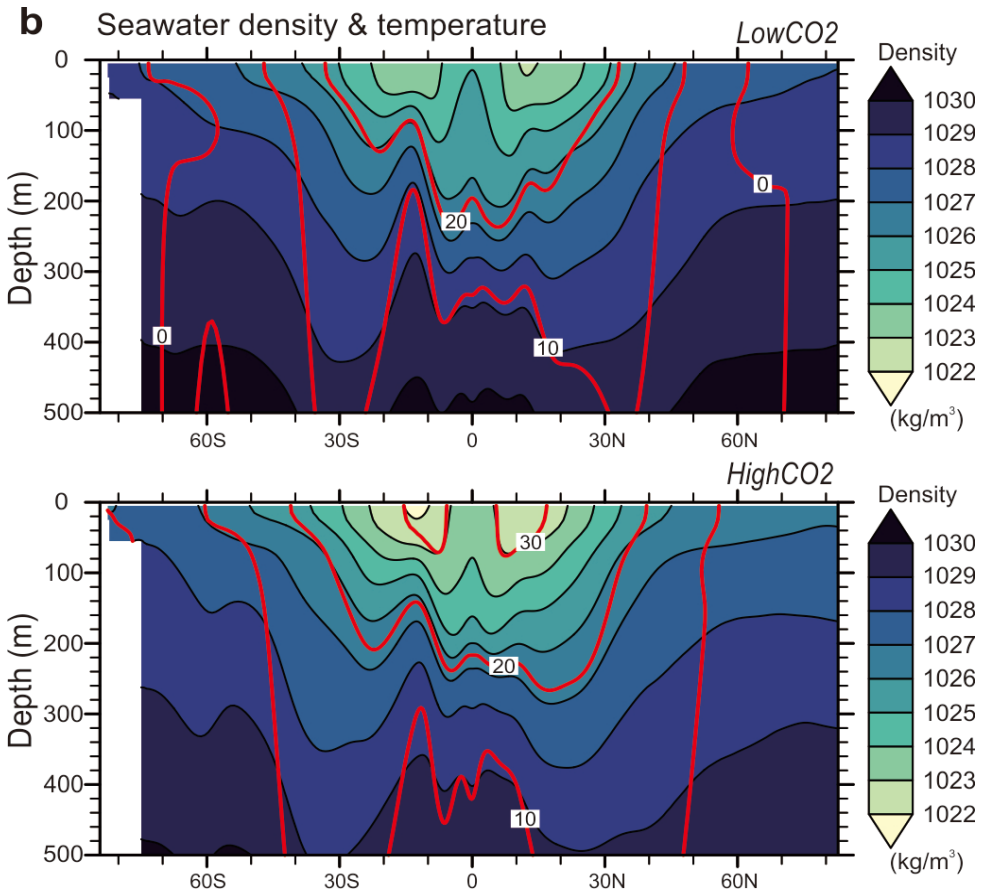
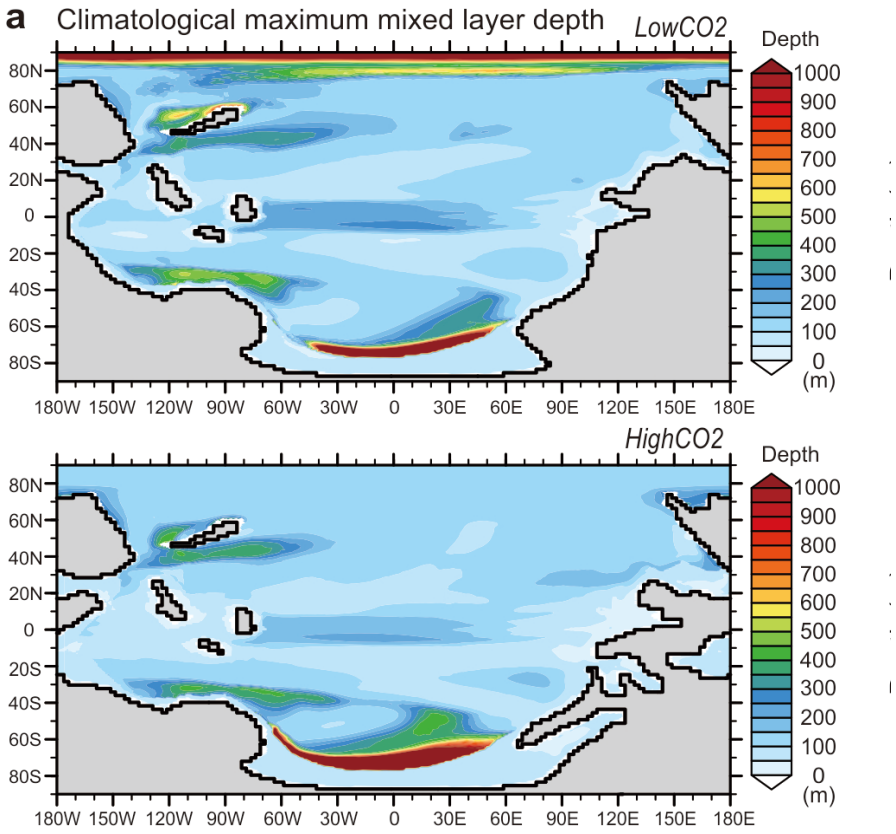


Warming in *HighCO2* strengthens the surface halocline and shoals the thermocline, inhibiting convection & ventilation in the upper ocean

Deep-water formation stops in the Northern Panthalassic Ocean with warming



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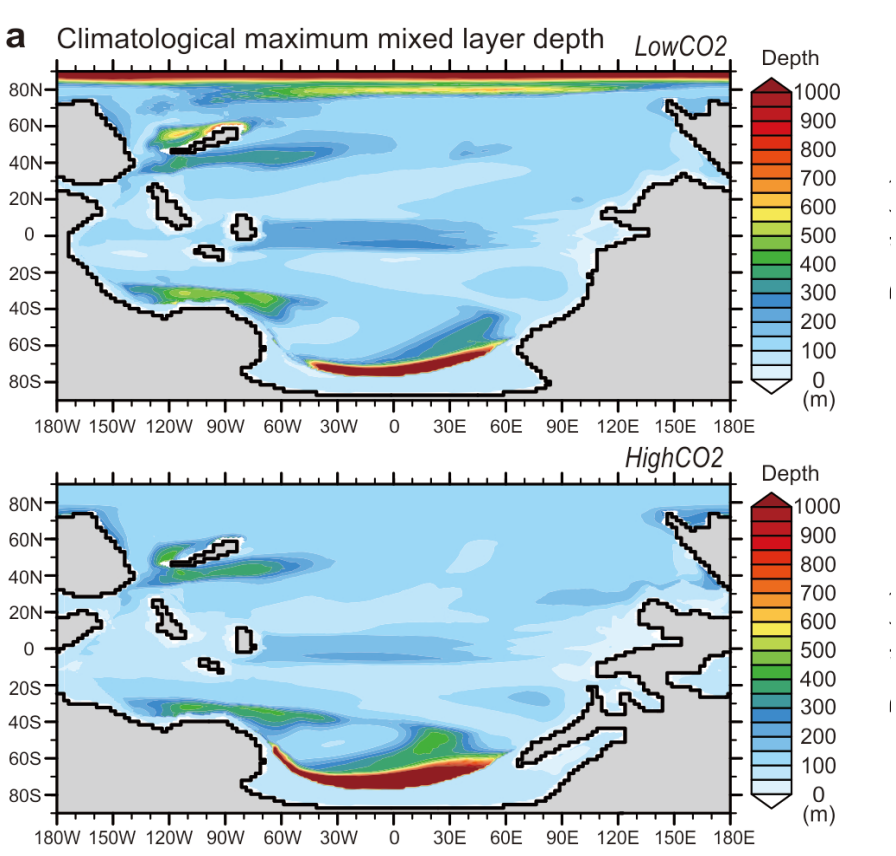
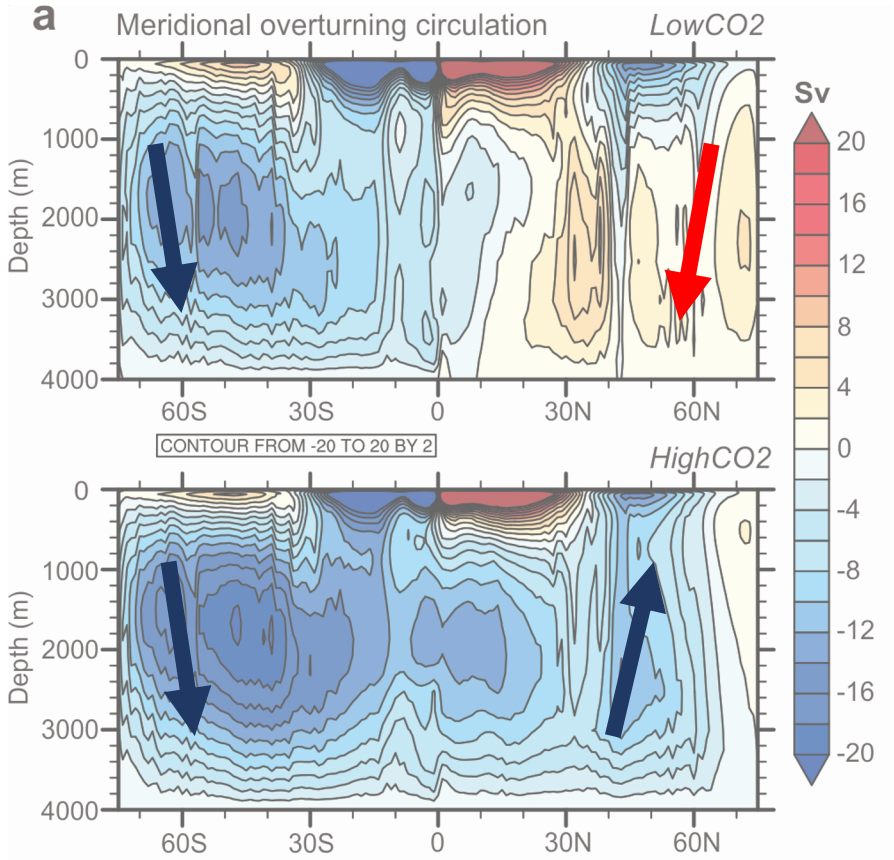
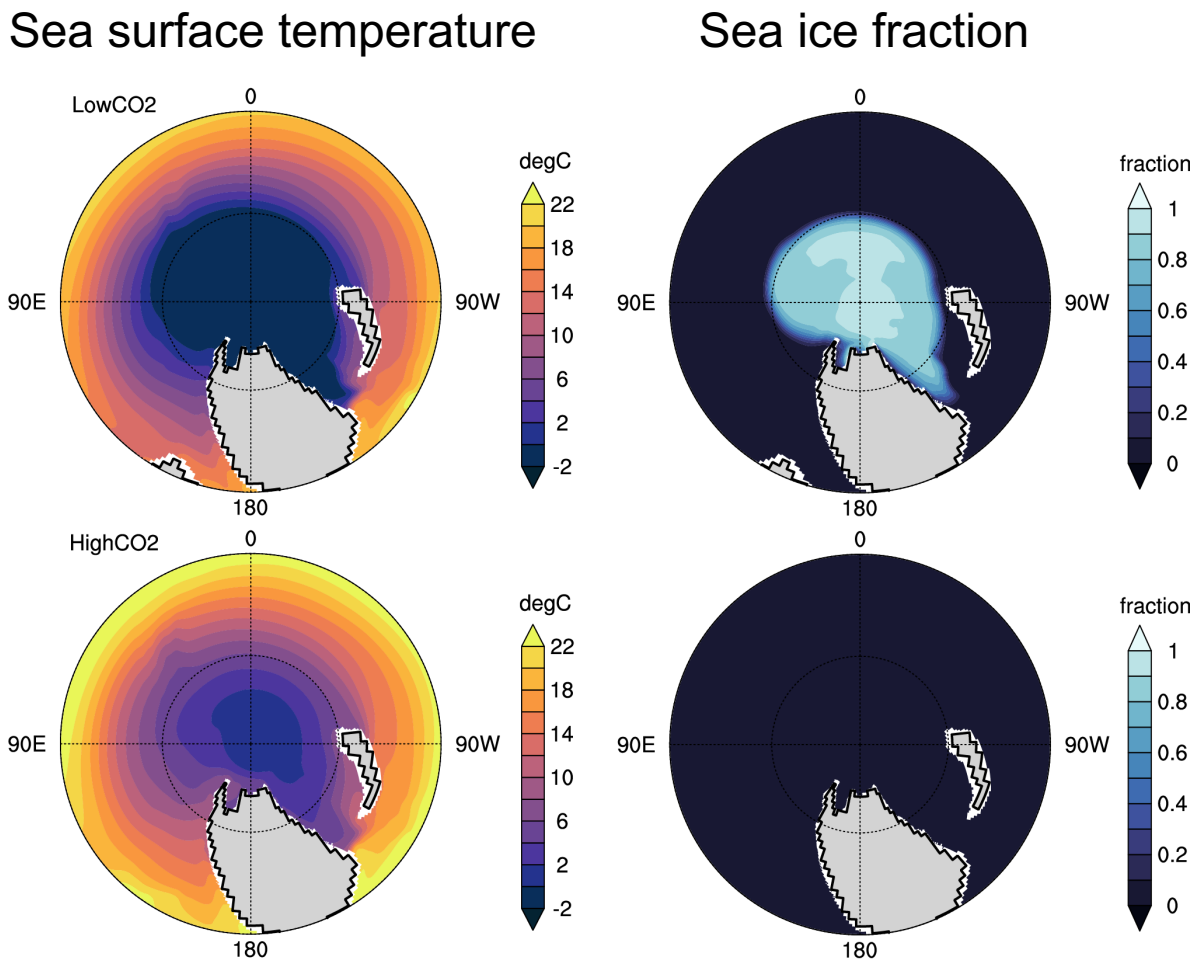


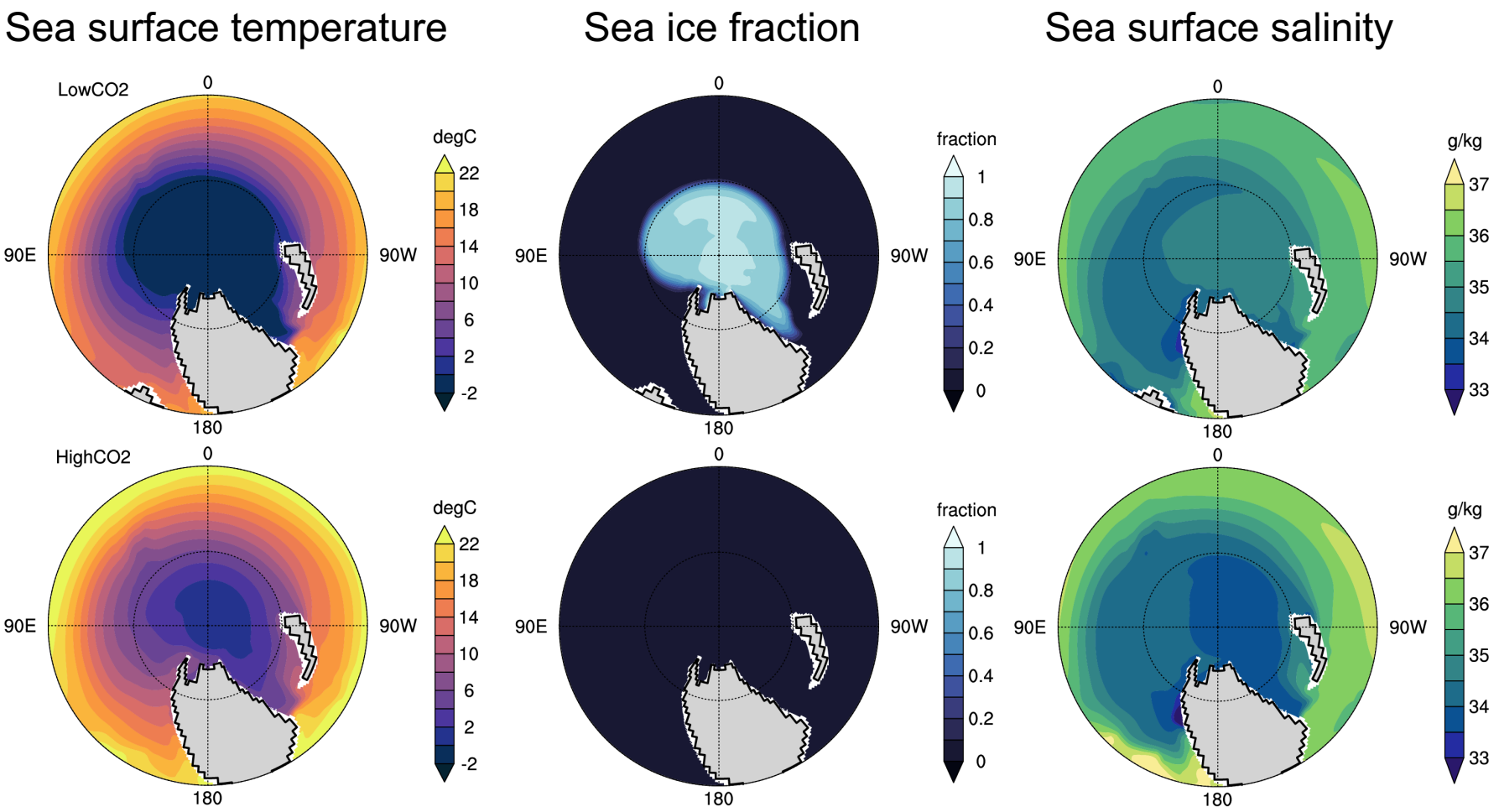


Warming inhibits sea ice formation in N. hemisphere



Warming inhibits sea ice formation in N. hemisphere

Brine rejection drives deep-water formation in the Northern Panthalassic Ocean of *LowCO2*



Warming reduces ventilation in Northern Panthalassic Ocean

- Simulations do not have active biogeochemistry
- *Ideal age tracer* in CESM tracks time since water mass has been in contact with the surface
- Idealized age of water masses typically correlates with dissolved O_2 in the deep (e.g., Winguth & Winguth, 2012)

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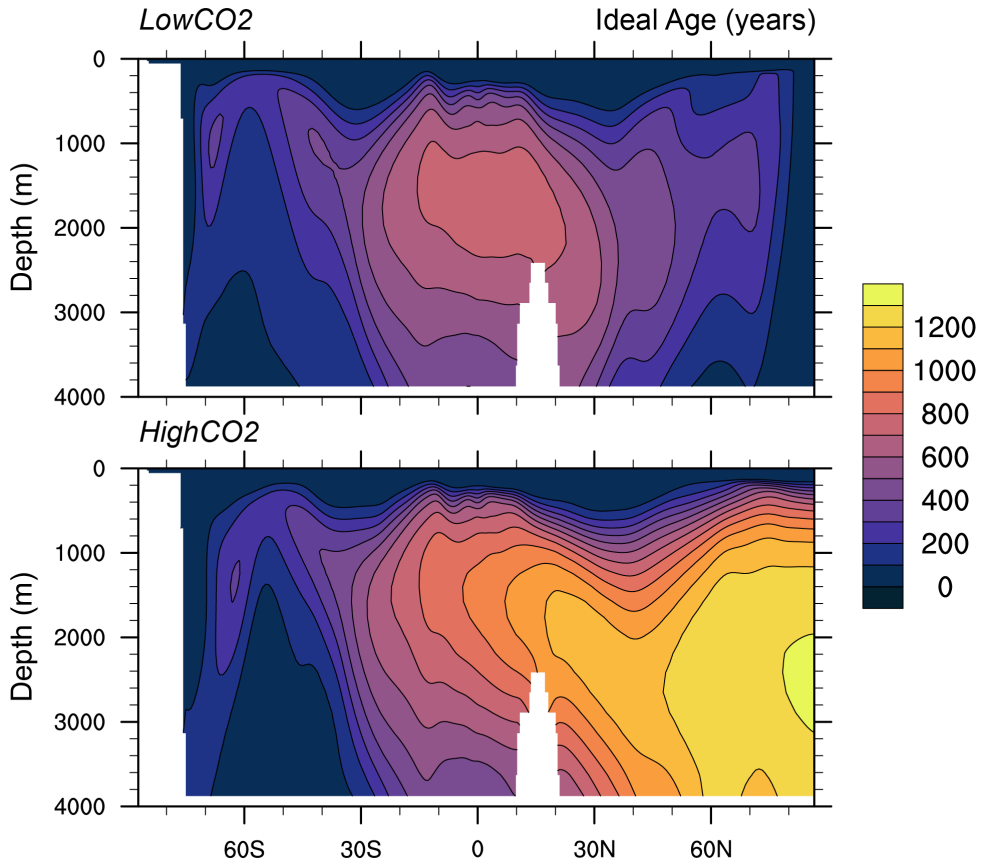
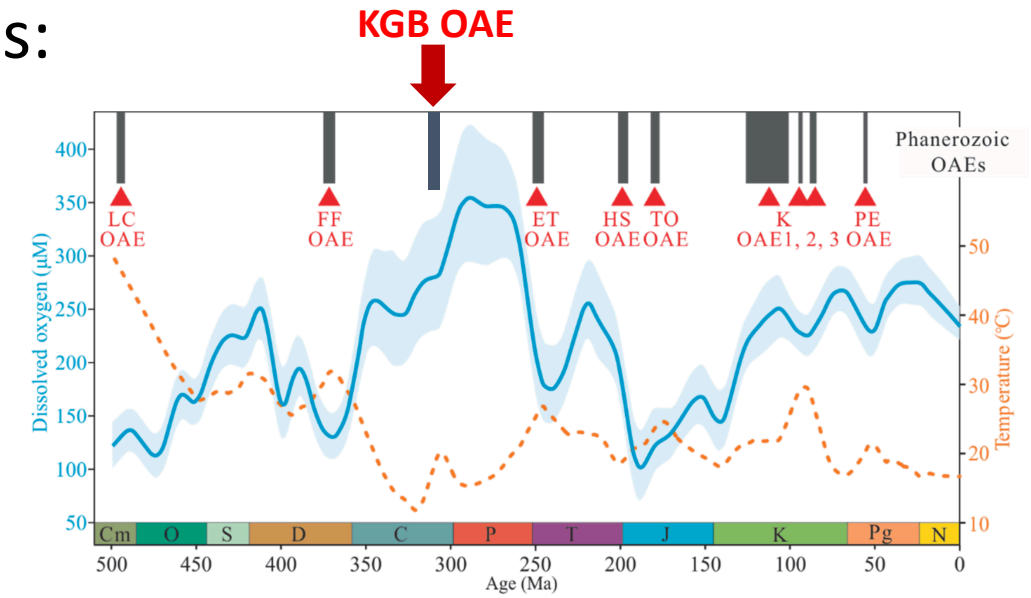


Conclusions & Future Directions

- Kasimovian–Gzhelian Boundary (~304 Mya) warming event led to widespread marine anoxia and can provide insight for warming induced ocean deoxygenation in an icehouse climate
- Two plausible mechanisms for O_2 loss:
  - Increased upper ocean stratification
  - Sluggish ocean circulation in NH

Future directions: CESM simulations with active biogeochemistry needed to directly address dissolved oxygen



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Thanks for listening ☺

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