Controls on Permo-Carboniferous tropical climate in Pangea*: *Insights from iCESM*

**And some basic parallels drawn with the Quaternary*

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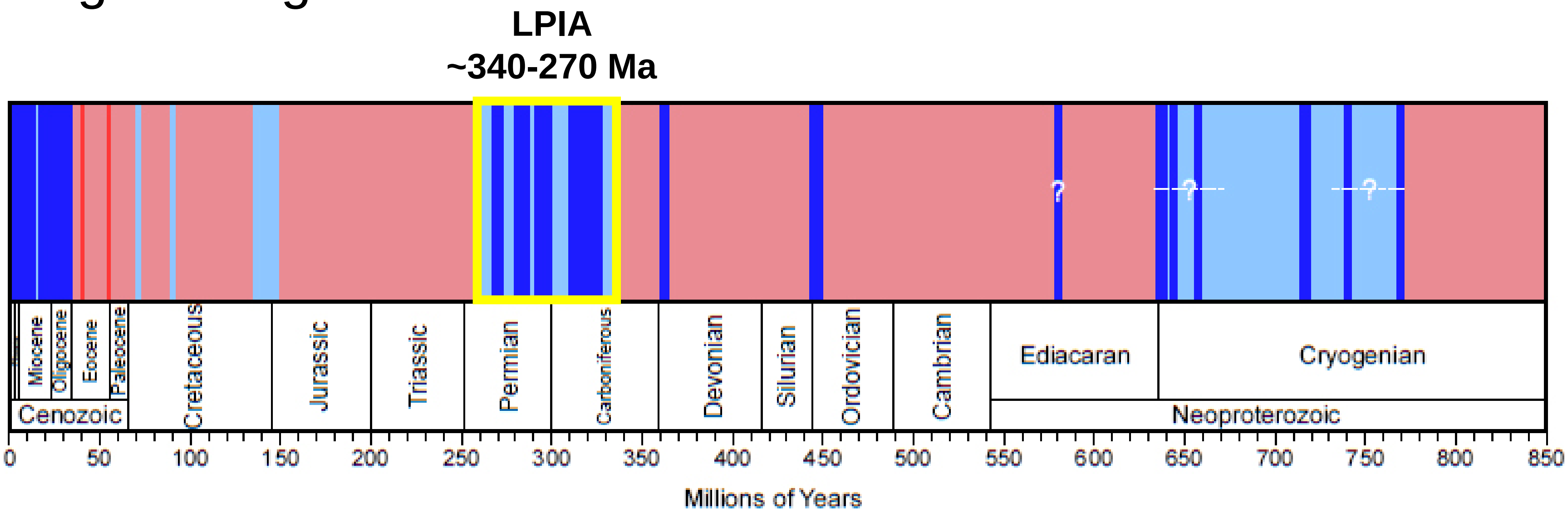
Water Isotopes and Climate Workshop 2019

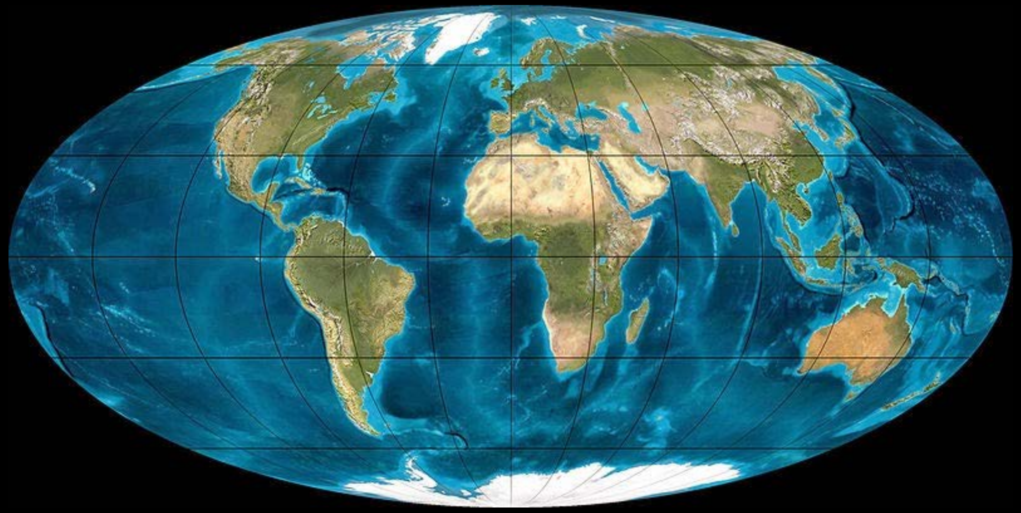
Icehouses are rare

- Icehouse periods make up <25% of the past billion years
- Late Paleozoic Ice Age (LPIA) is the last analogue of a deglaciating world

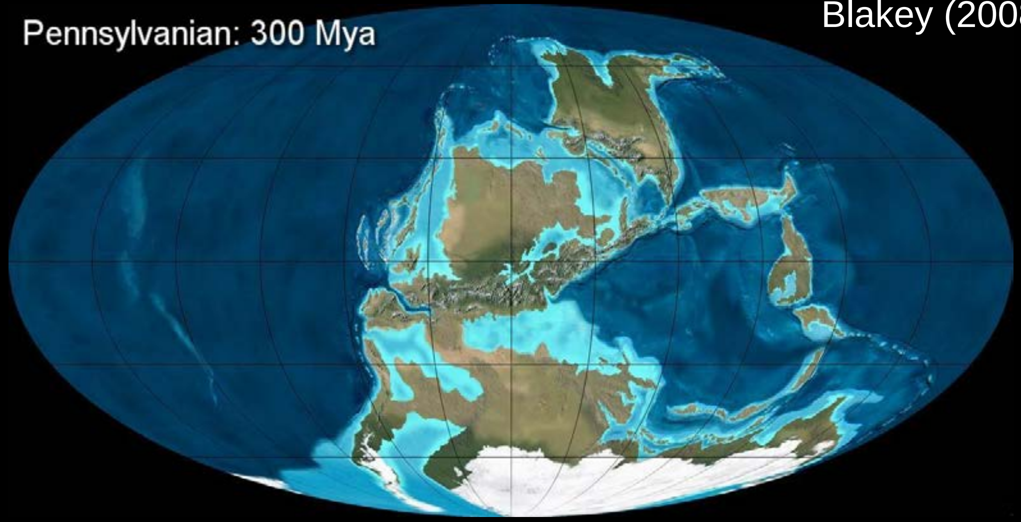


LPIA very different than Quaternary

1. Supercontinental geography
   - Most land in the southern hemisphere
   - Large equatorial mountain range



Blakey (2008)



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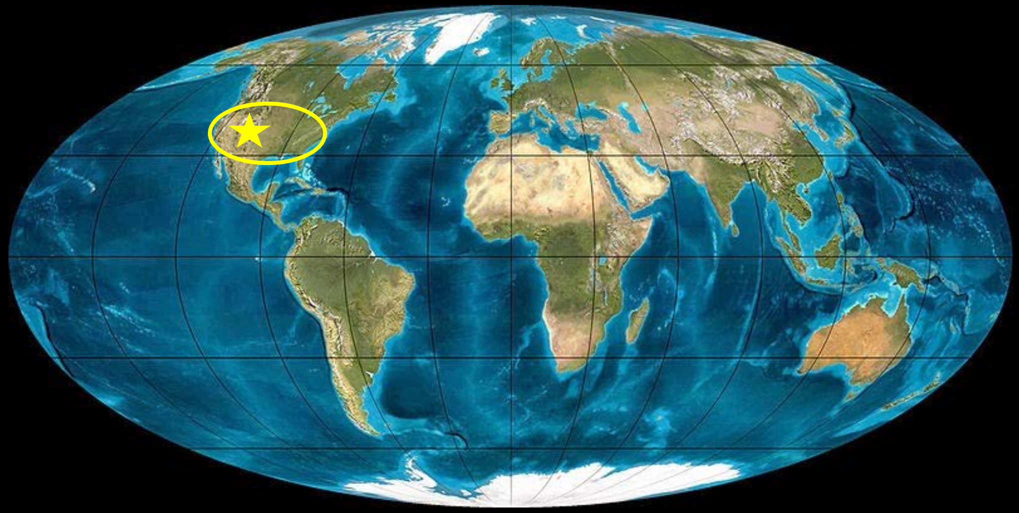

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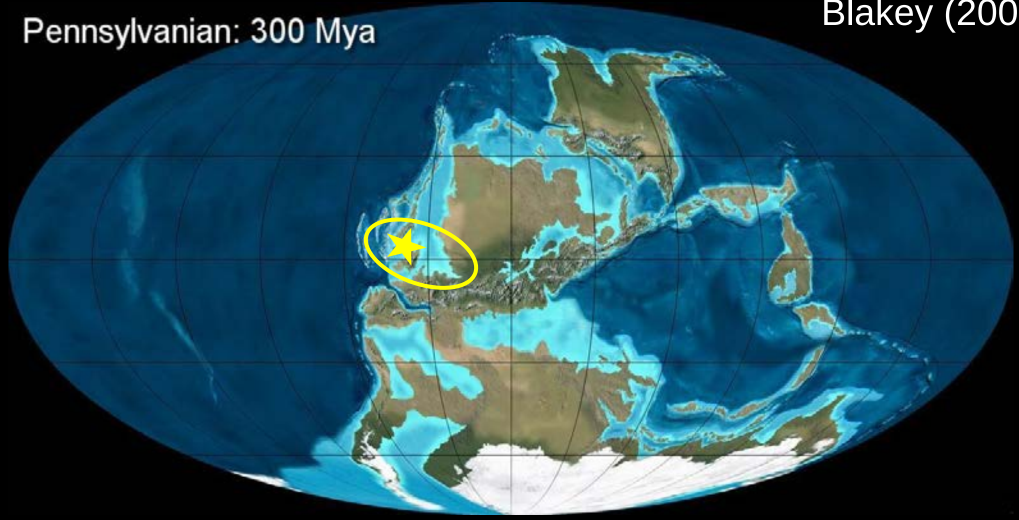

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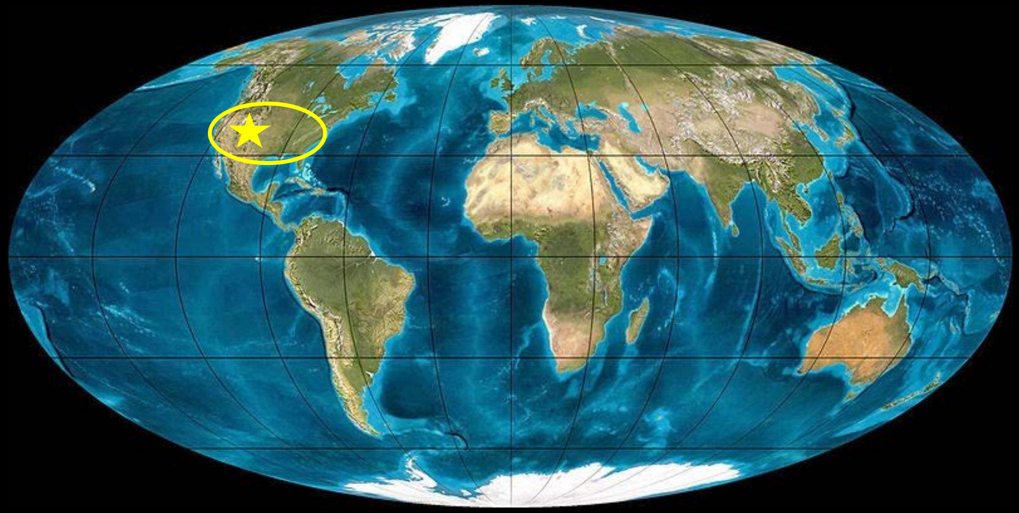

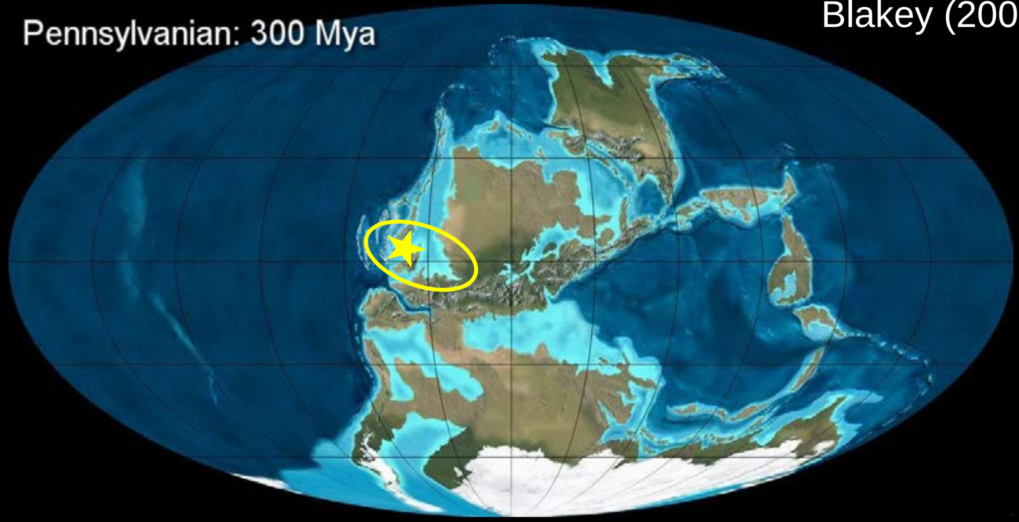

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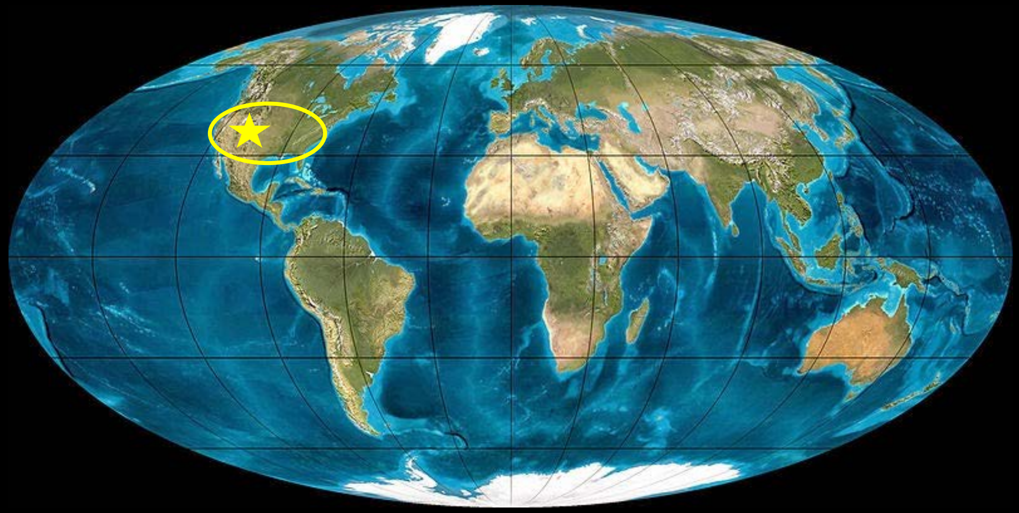

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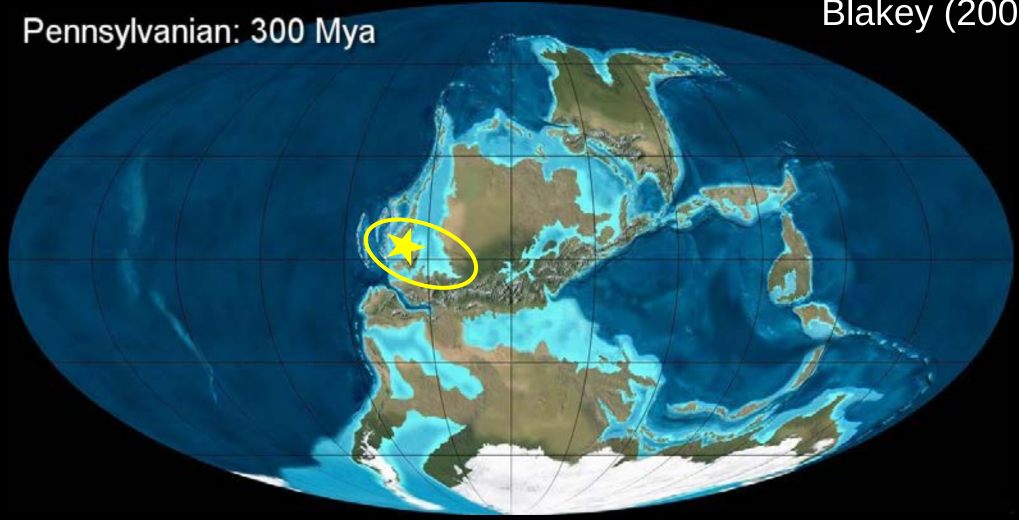

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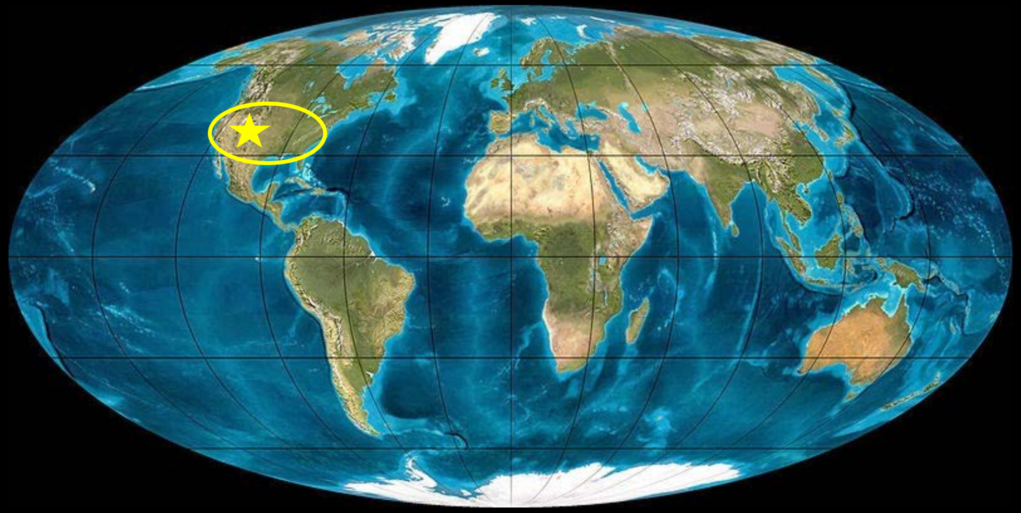
4. Glacial geography
   - Virtually all land ice in southern hemisphere



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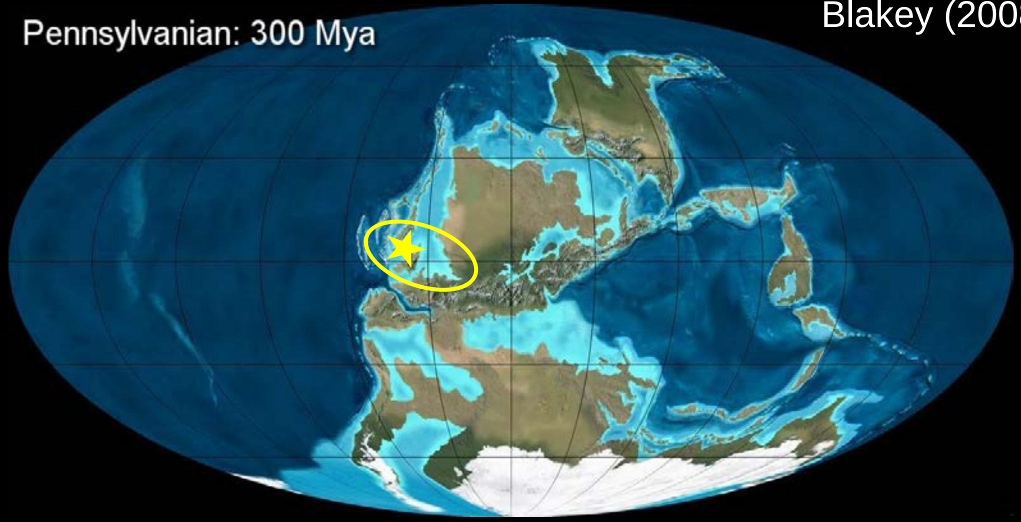
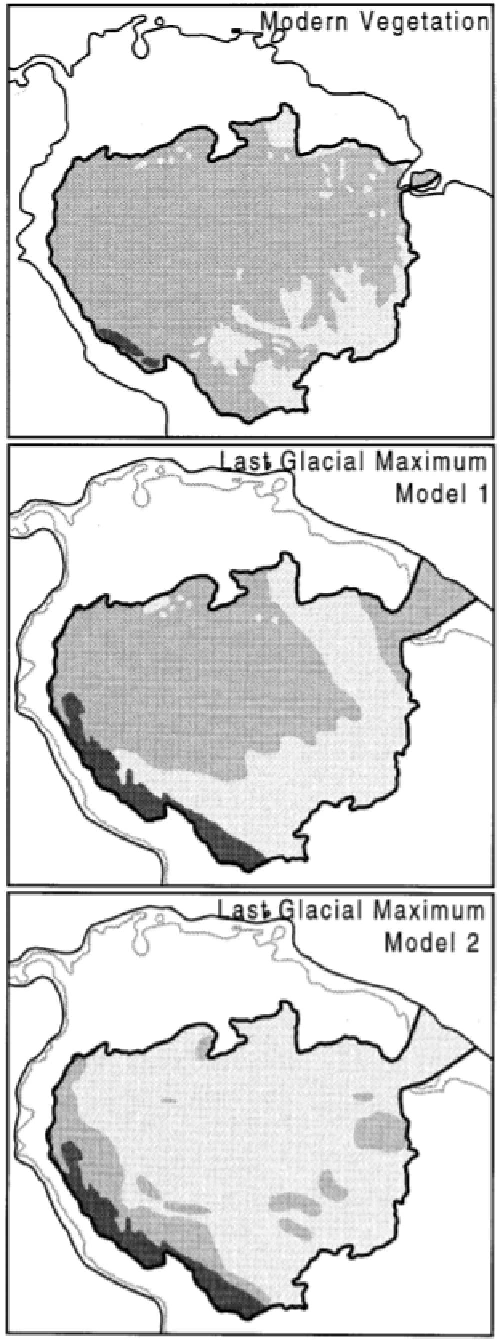


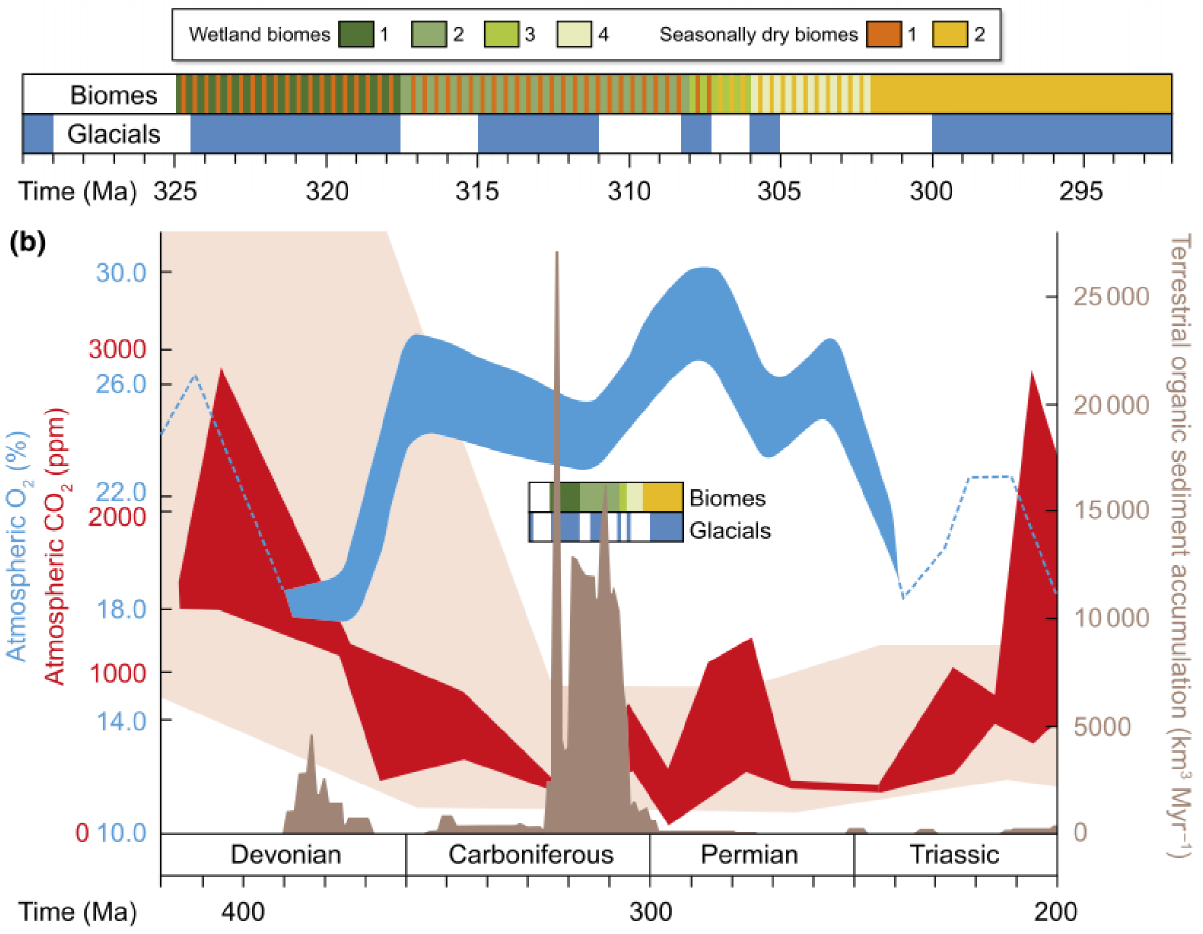
Tropical vegetation during the Quaternary



- The response of tropical vegetation to glacial-interglacial cycles, even within a single region, is nonuniform and complex
  - E.g. South America

Haberle & Maslin (1999)

Tropical vegetation during the Late Paleozoic



Montañez (2016)

- Shifts in tropical biomes occurred over glacial-interglacial cycles, but whether the tropics were relatively wet or dry during glacial intervals is debated

Ultimate Questions

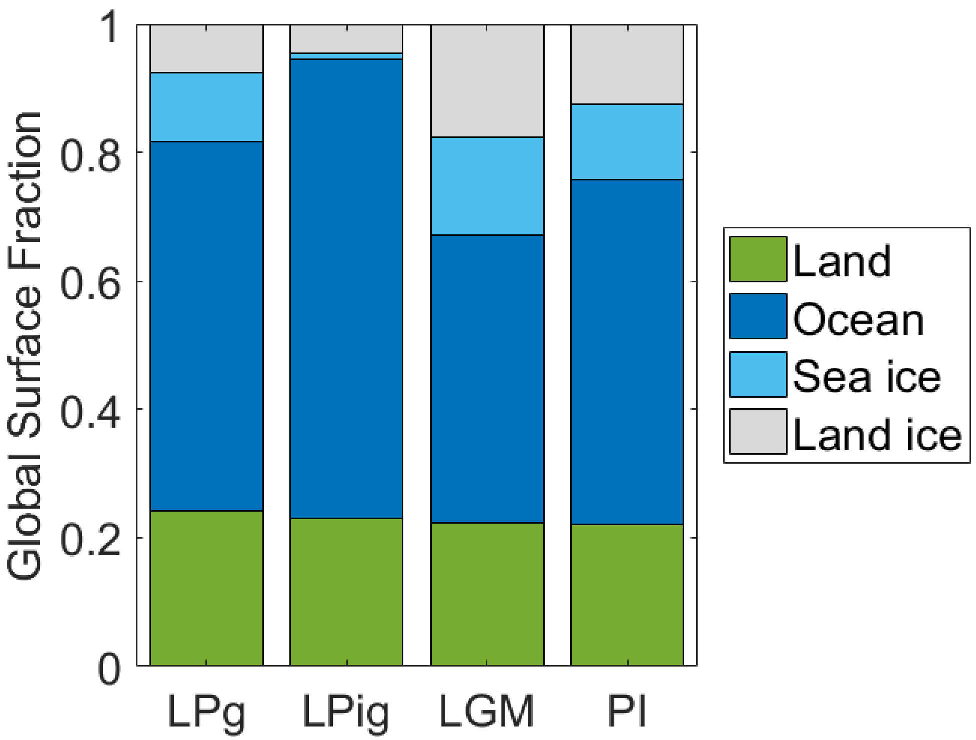
- What climate processes control the Pangean tropics over glacial-interglacial cycles?
  - Despite their differences, are there any similarities between the tropical hydroclimate during the Late Paleozoic and Quaternary?
  - How can water isotopes in CESM help enrich our understanding?

Glacial and interglacial simulations

Four fully-coupled water isotope-enabled CESM simulations:

1. **LPig** = Late Paleozoic interglacial
2. **LPg** = Late Paleozoic glacial
3. **PI** = Pre-Industrial (interglacial)
4. **LGM** = Last Glacial Maximum (glacial)

	LPig	LPg	PI	LGM
Land ice geography	Unipolar low	Unipolar high	Bipolar low	Bipolar high
Radiative forcing	792 ppb CH_4 276 ppb N_2O 560 ppm CO_2 97.5% solar	792 ppb CH_4 276 ppb N_2O 280 ppm CO_2 97.5% solar	792 ppb CH_4 276 ppb N_2O 280 ppm CO_2 100% solar	350 ppb CH_4 200 ppb N_2O 185 ppm CO_2 100% solar
Land-sea distribution	Supercontinent (high sea level)	Supercontinent (low sea level)	Modern (high sea level)	Modern (low sea level)



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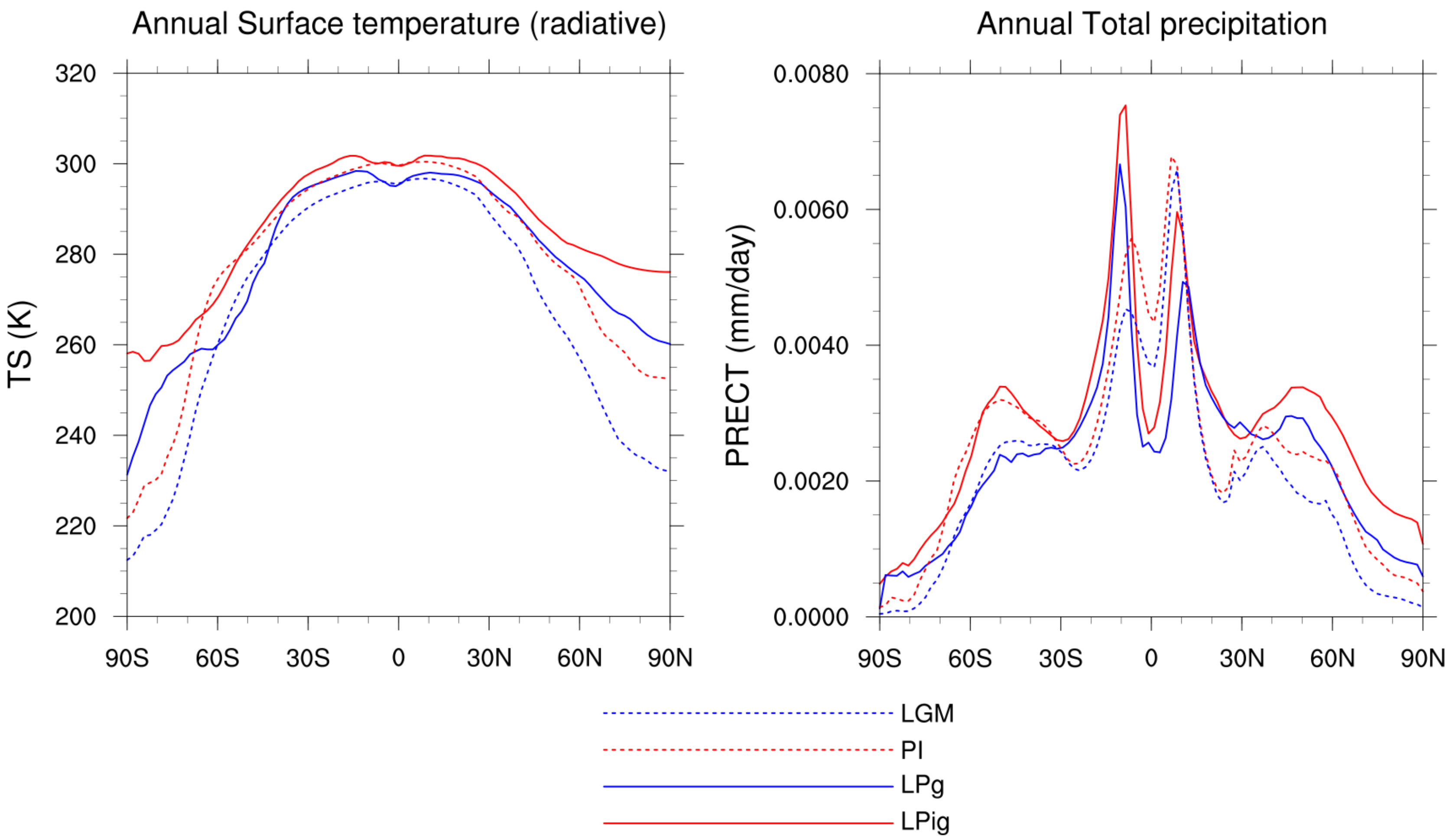
Land-sea distribution	Supercontinent (high sea level)	Supercontinent (low sea level)	Modern (high sea level)	Modern (low sea level)

Vegetation and orbital parameters are the same, so we are testing the *combined* effects of three main differences

Globally atmosphere is moister and rainier with warmer temperatures



Quaternary:

2.4%↑ K^{-1} warming

Late Paleozoic:

3.6%↑ K^{-1} warming

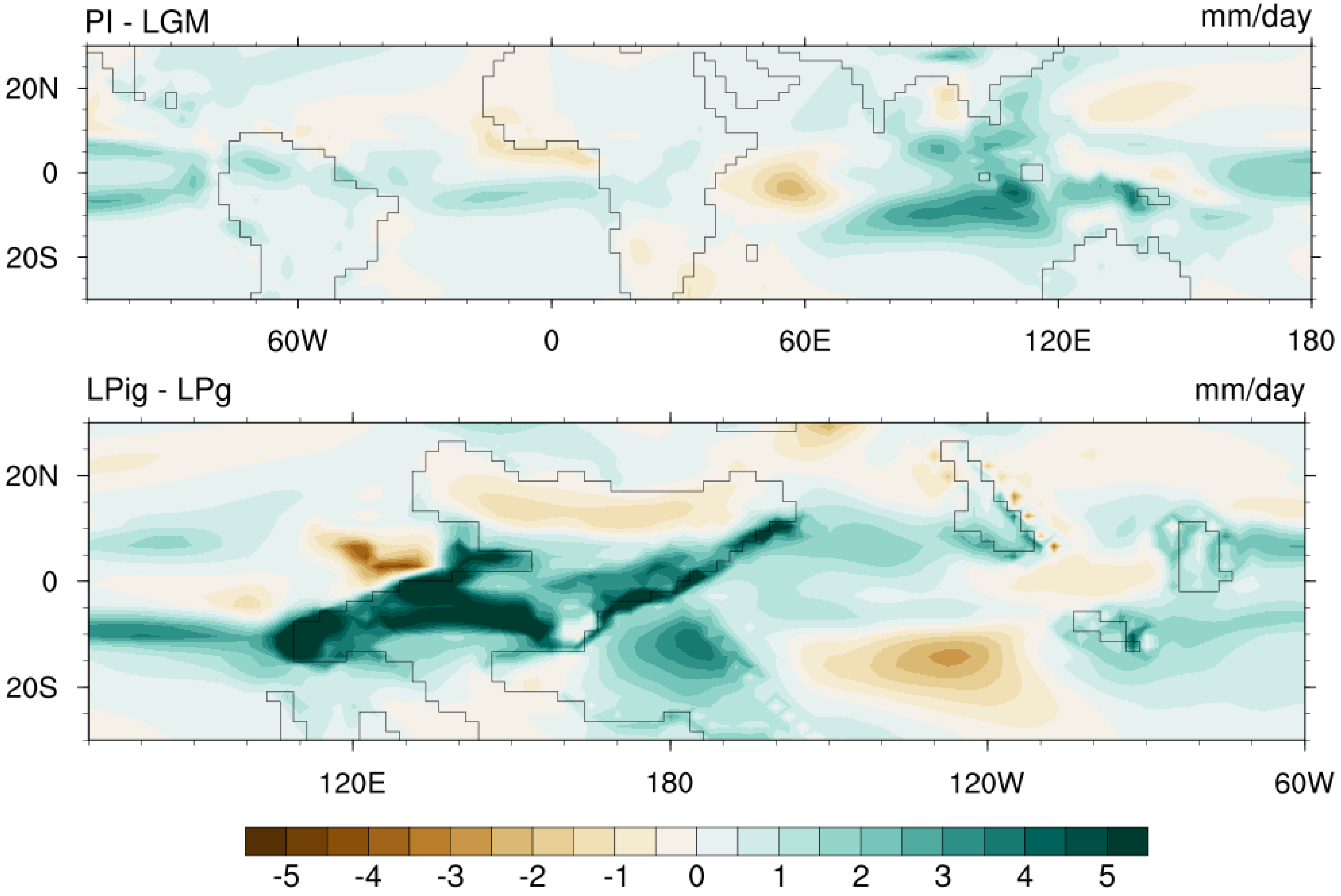
Interglacial phases have higher tropical rainfall

Quaternary:

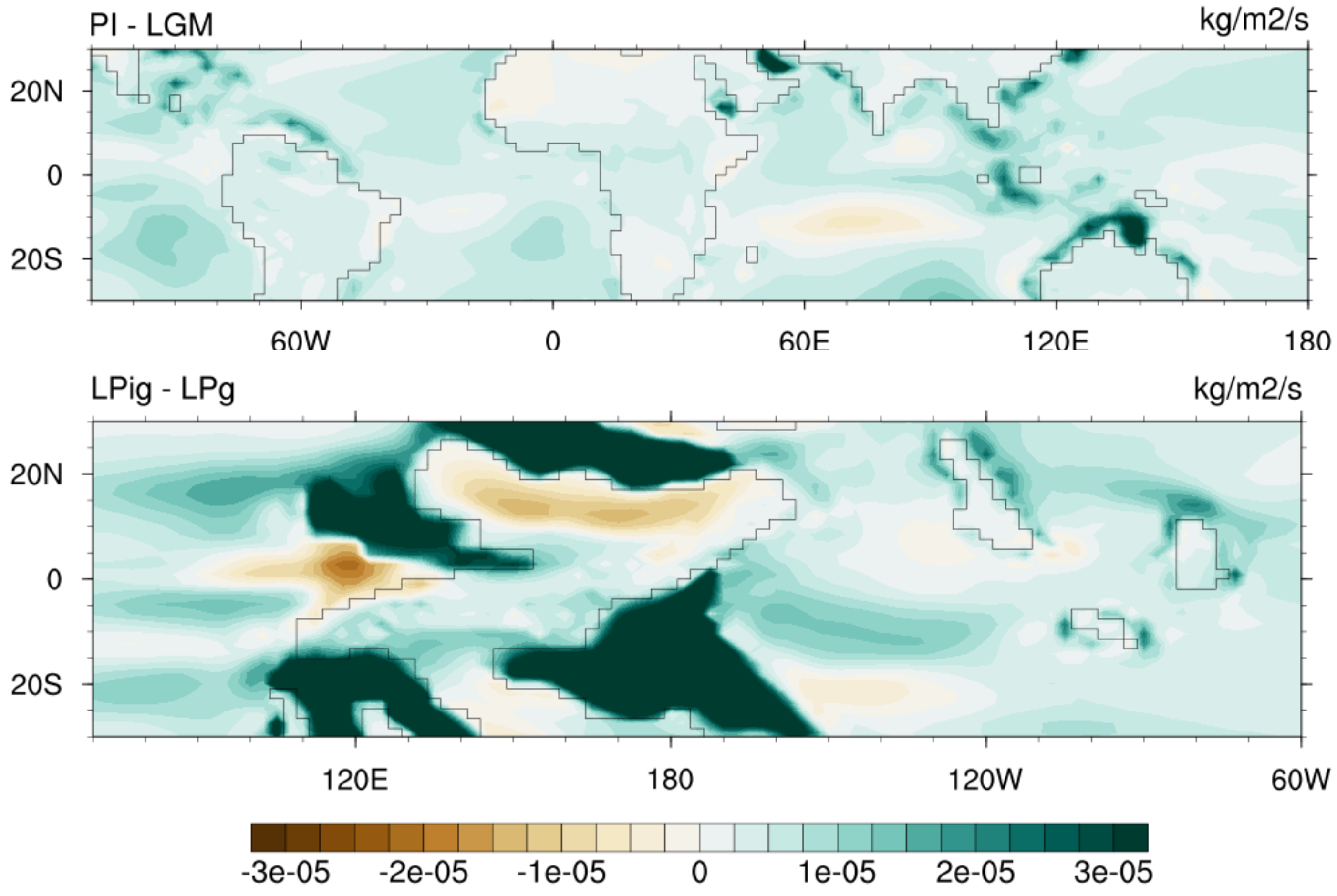
3.2%↑ K^{-1} warming

Late Paleozoic:

6.4%↑ K^{-1} warming



Higher evaporation in interglacial states



Annual surface evaporative flux increases with higher surface temperatures, particularly in coastal regions with sea level rise

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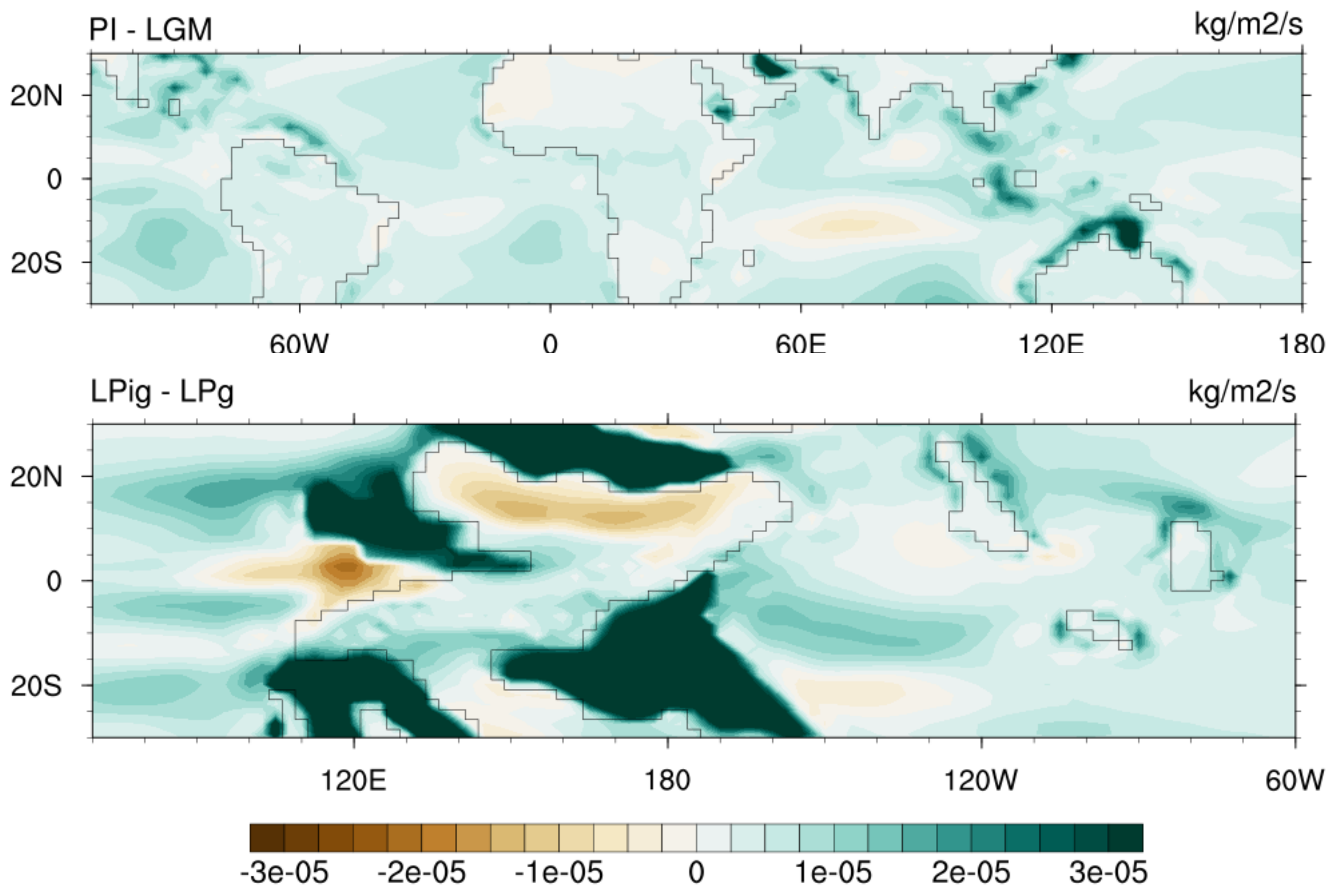
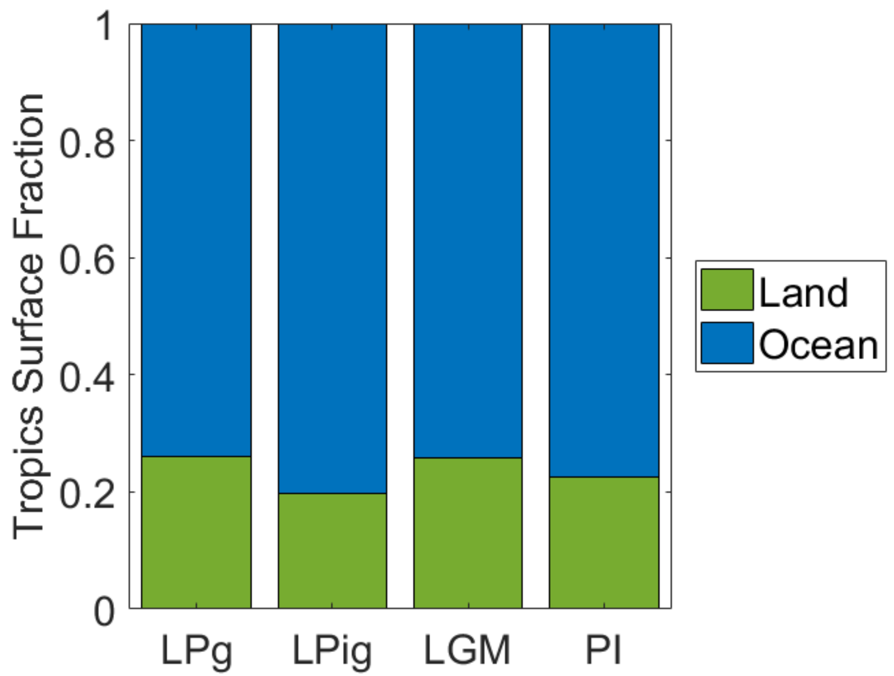
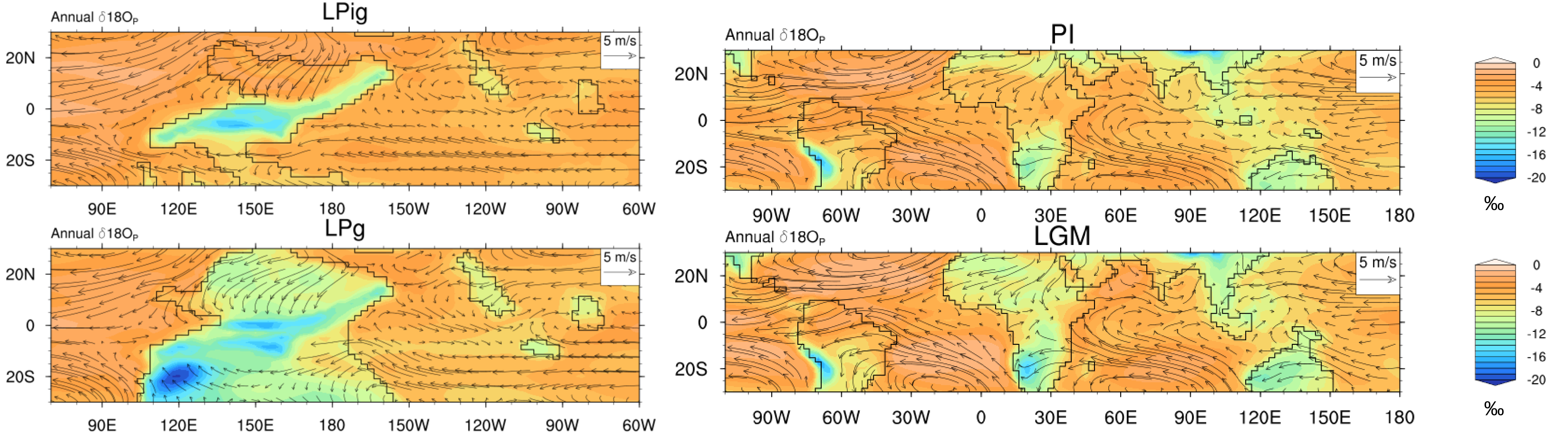




Fraction of ocean surface increases by
32% in LP
14% in Quaternary

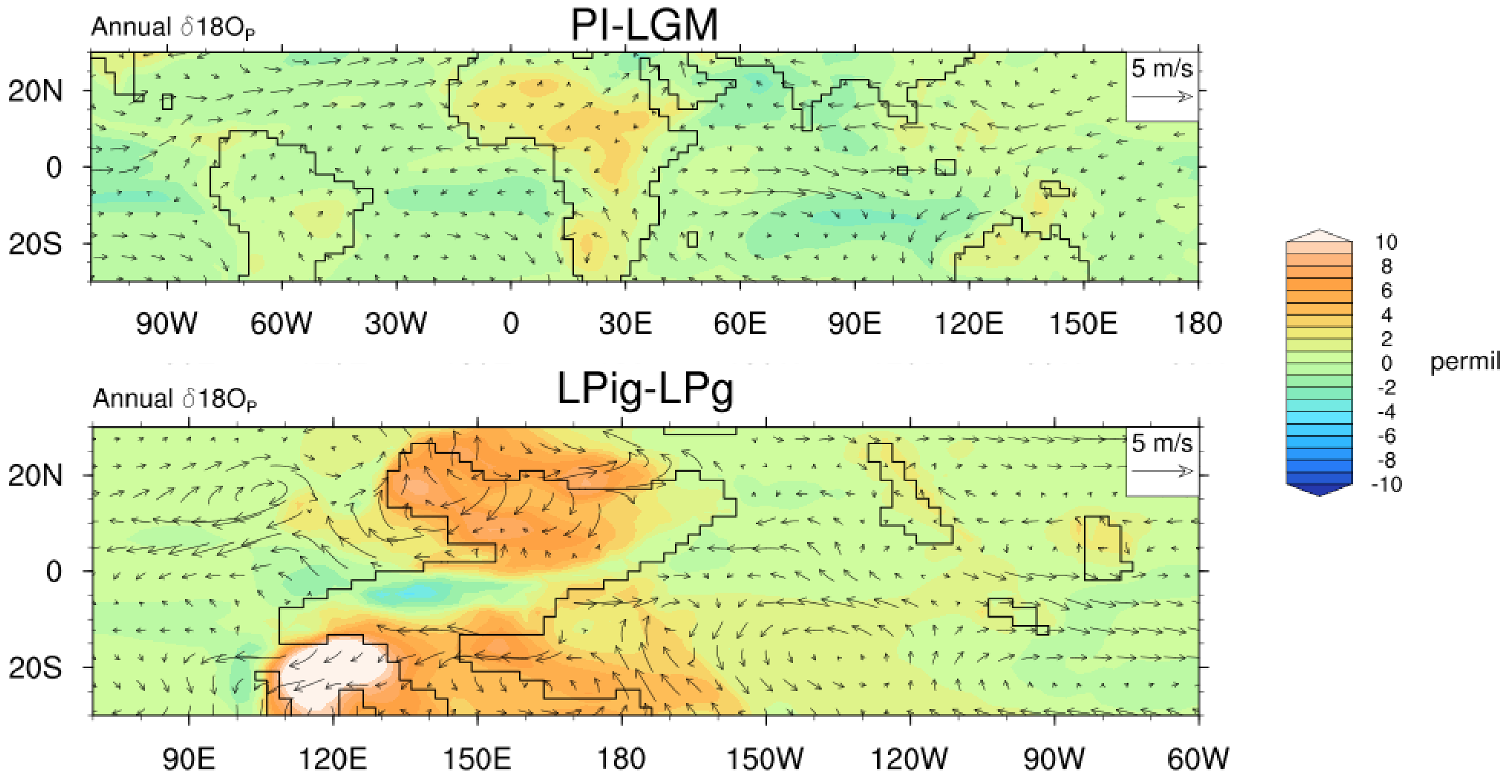
Lowland precipitation δ¹⁸O is depleted in glacial intervals



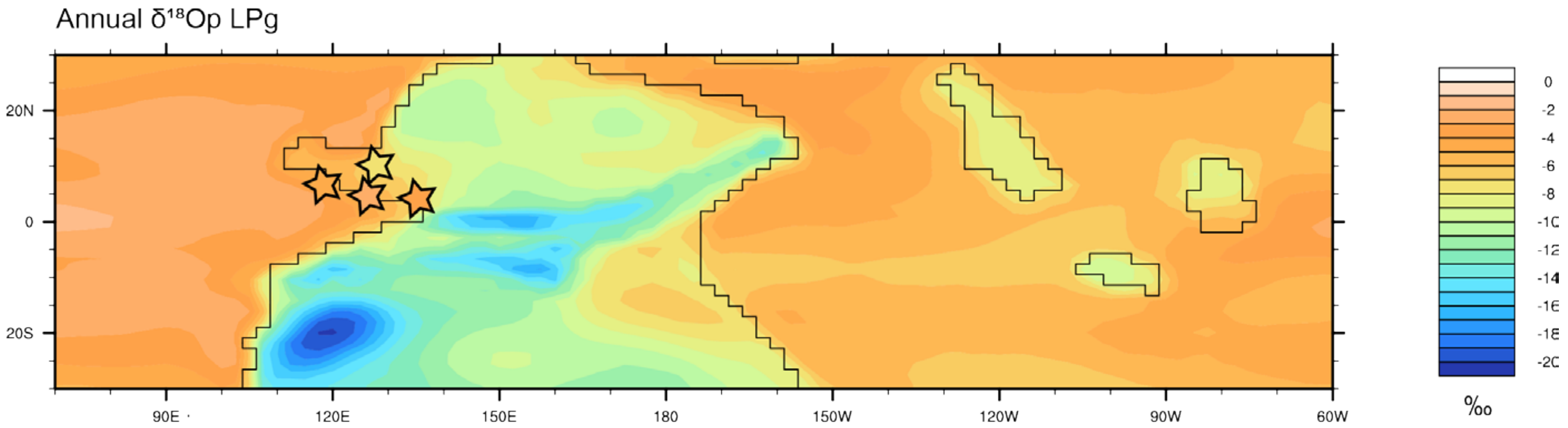
Depleted inland precipitation δ¹⁸O reflects increased continentality and reduced temperature

Inland regions exhibit the largest changes in precipitation $\delta^{18}O$

- No change in coastal precipitation $\delta^{18}O$ where moisture source is unaffected by changes in sea level
  - Would not expect $\delta^{18}O_p$ reconstructions from these regions to have large signal in deep time



Model-proxy comparisons of $\delta^{18}O_p$ not possible at present for the Late Paleozoic



- Pedogenic mineral $\delta^{18}O$ formed in fossil soils have only been used to reconstruct $\delta^{18}O_p$ in western Pangea (Tabor & Montanez, 2002; Rosenau et al., 2013)
- iCESM $\delta^{18}O_p$ can be used to identify regions areas with large isotopic change between glacial-interglacial intervals

Preliminary Conclusions

- Late Paleozoic interglacials generally more wet in tropics (in absence of orbital fluctuations or vegetation change)
  - Surface warming with higher CO_2 produces increased evaporation
  - Higher sea level provides robust nearby moisture source for monsoons (even if they are weaker)

- iCESM can help identify regions of interest for reconstructions of $\delta^{18}O_p$ in deep time (e.g. LPIA) where the isotopic signal is sensitive to climate change

Future Work in the Late Paleozoic

- Quantify individual impacts of CO_2, sea level, and ice volume associated with glacial and interglacial states on tropical climate change

- Impact of glacial-interglacial orbital fluctuations on tropical hydroclimate
  - Changes in monsoons induced by orbital fluctuations could explain regionally wetter conditions during a glacial