Revisiting western US hydroclimate during the last deglaciation using iTraCE

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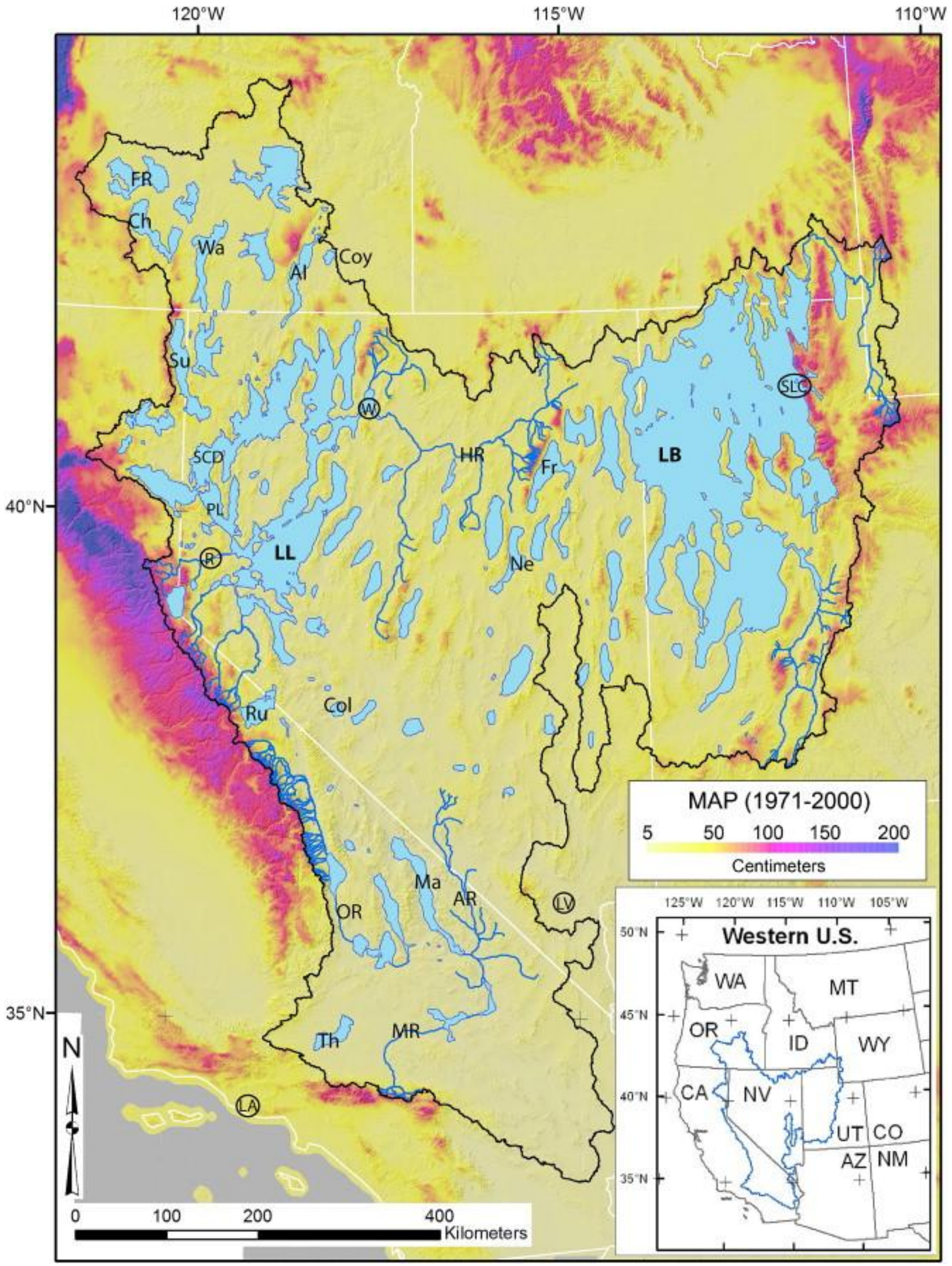
Western US Climate during LGM

- It has been known since the 19th century that the western US sustained large lakes during the last ice age (Russell 1885, Gilbert, 1890).
- Water budget analyses indicate the lakes required 70 - 140% higher rainfall levels to be sustained (Ibarra et al. 2014, Hostetler et al. 1990).
- The cause of wetter conditions remained enigmatic until the advent of climate modeling.

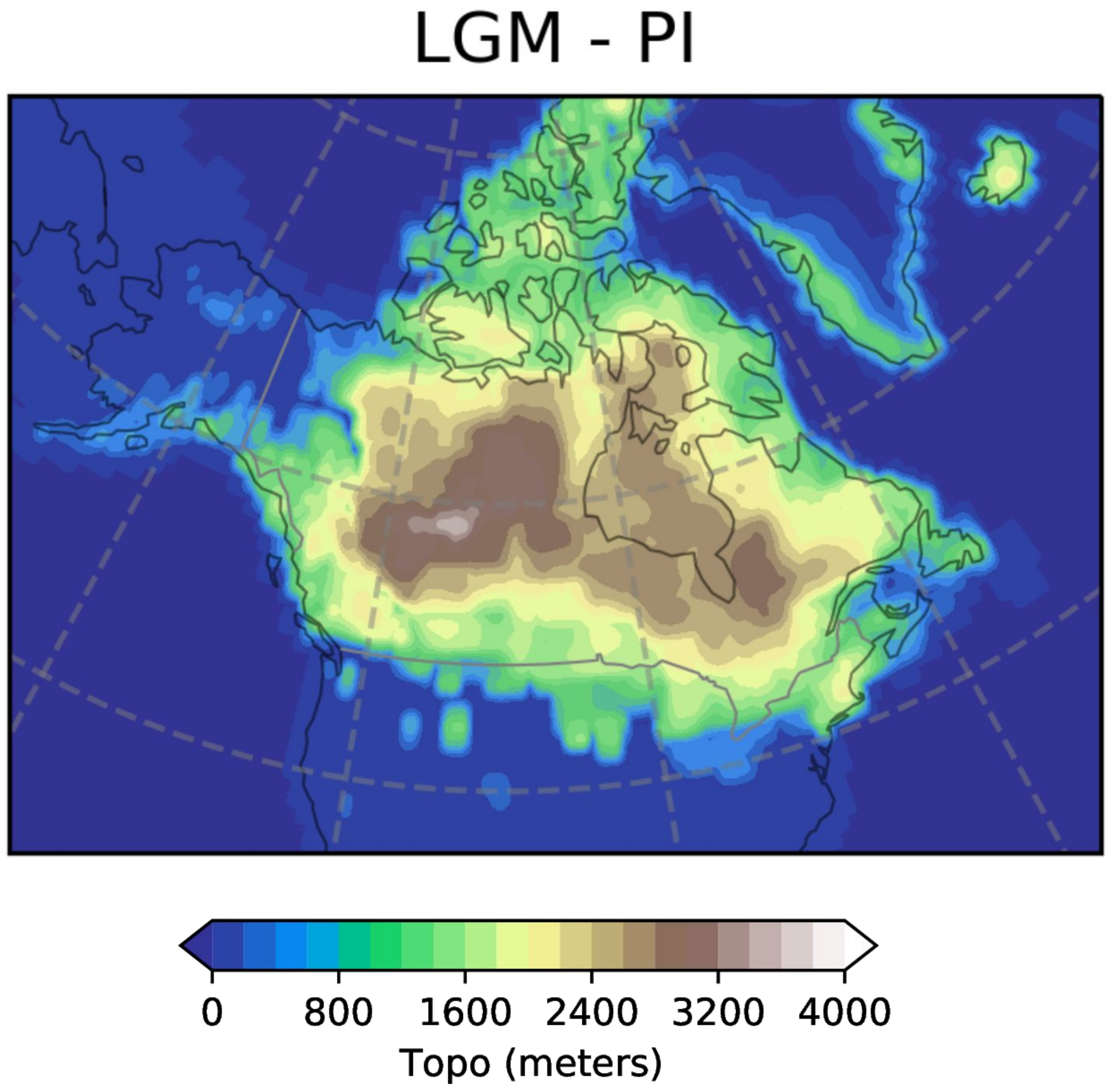


Reconstructed Pluvial Lakes
Over the Great Basin

Reheis et al. 2014

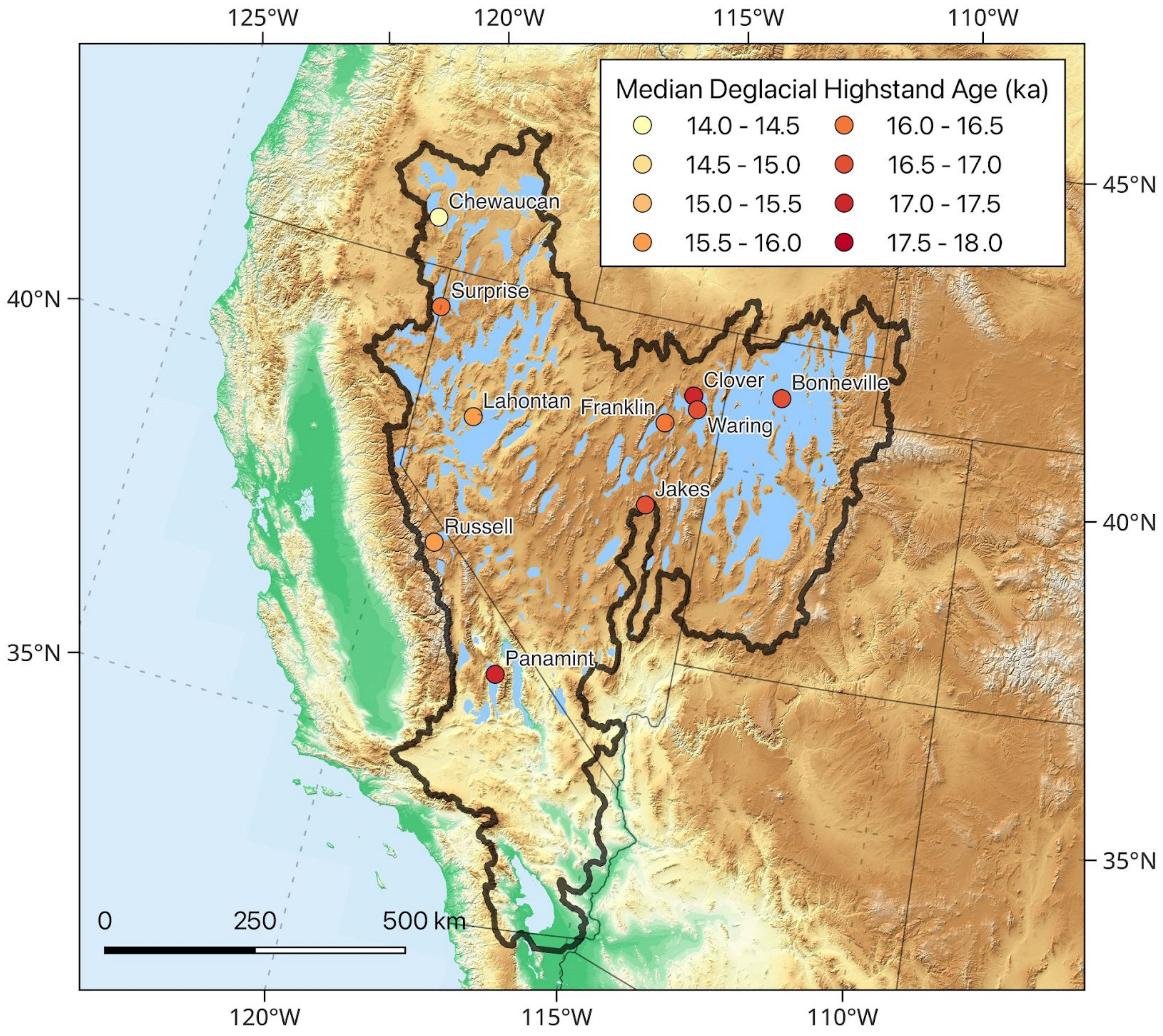
North American Ice Sheets

- The presence of the North American ice sheets was the largest driver of regional climate change.
- The 3km thick Laurentide ice sheet covered much of Canada as well as Chicago and New York.
- Modeling studies indicate the atmospheric circulation was strongly influenced by the presence of the Northern-hemisphere ice-sheets.
  (e.g., Kutzbach and Wright 1985, Manabe and Broccoli 1985, COHMAP Members, 1988; or more recently; Amaya et al. 2022, Brady et al. 2013, Lora et al. 2017, Kageyama et al. 2021)



ICE-6G (Peltier et al. 2015) ice sheet topography

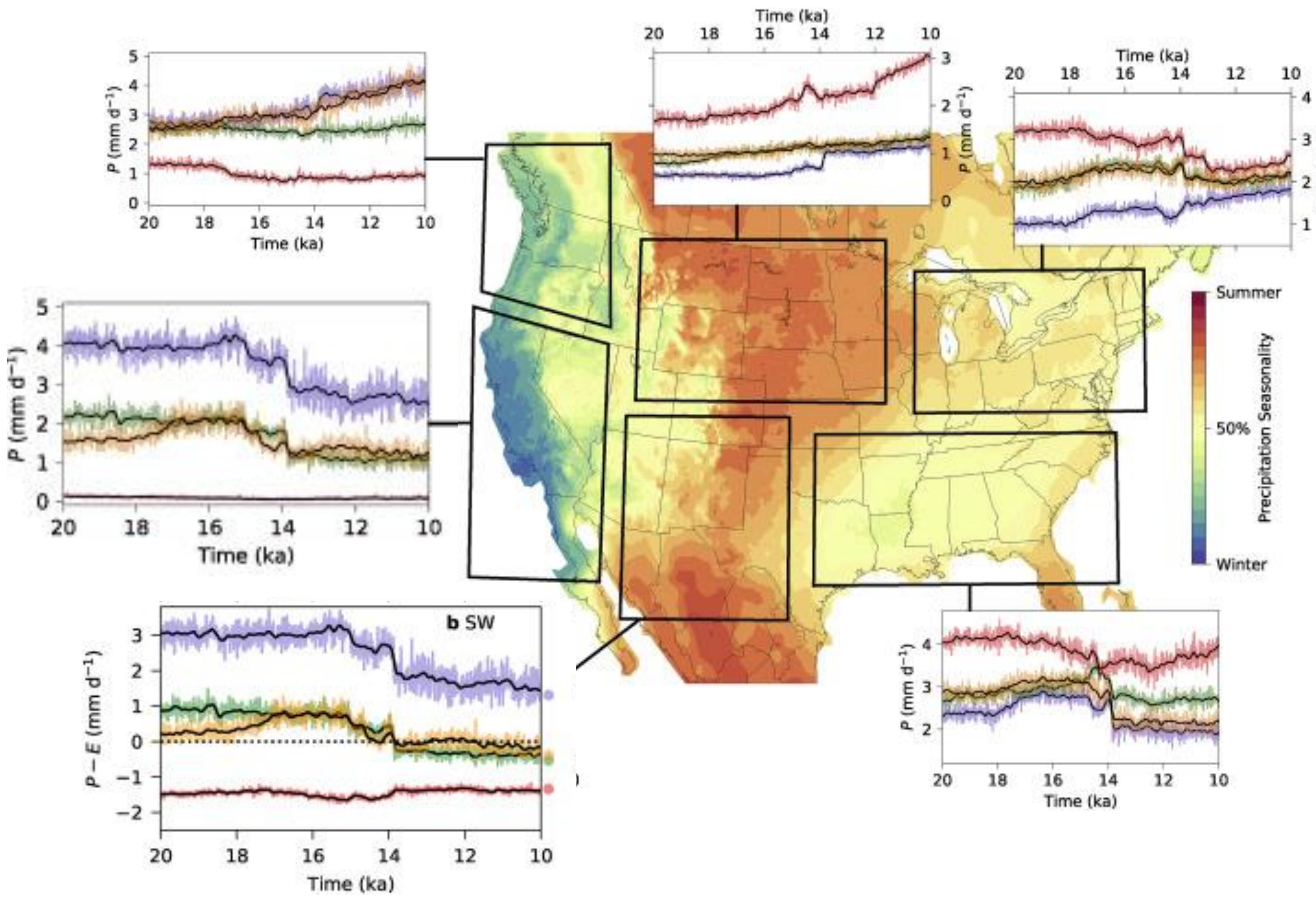
Lake Expansions during Deglaciation



Great Basin lake highstand ages (Fu 2023 GRL)
(adapted from compilation of McGee et al. 2018)

- Although conditions were wetter during ice ages, there is a more subtle feature in the proxy record.
- Great basin lakes reached their maximum size well after the LGM, generally between 15-18 ka.
- Some compilations indicate lakes in the northwest reach highstands at a later time compared to the southeast.
- The reasons for the delayed timing of lake expansions has remained unclear.

Previous Studies

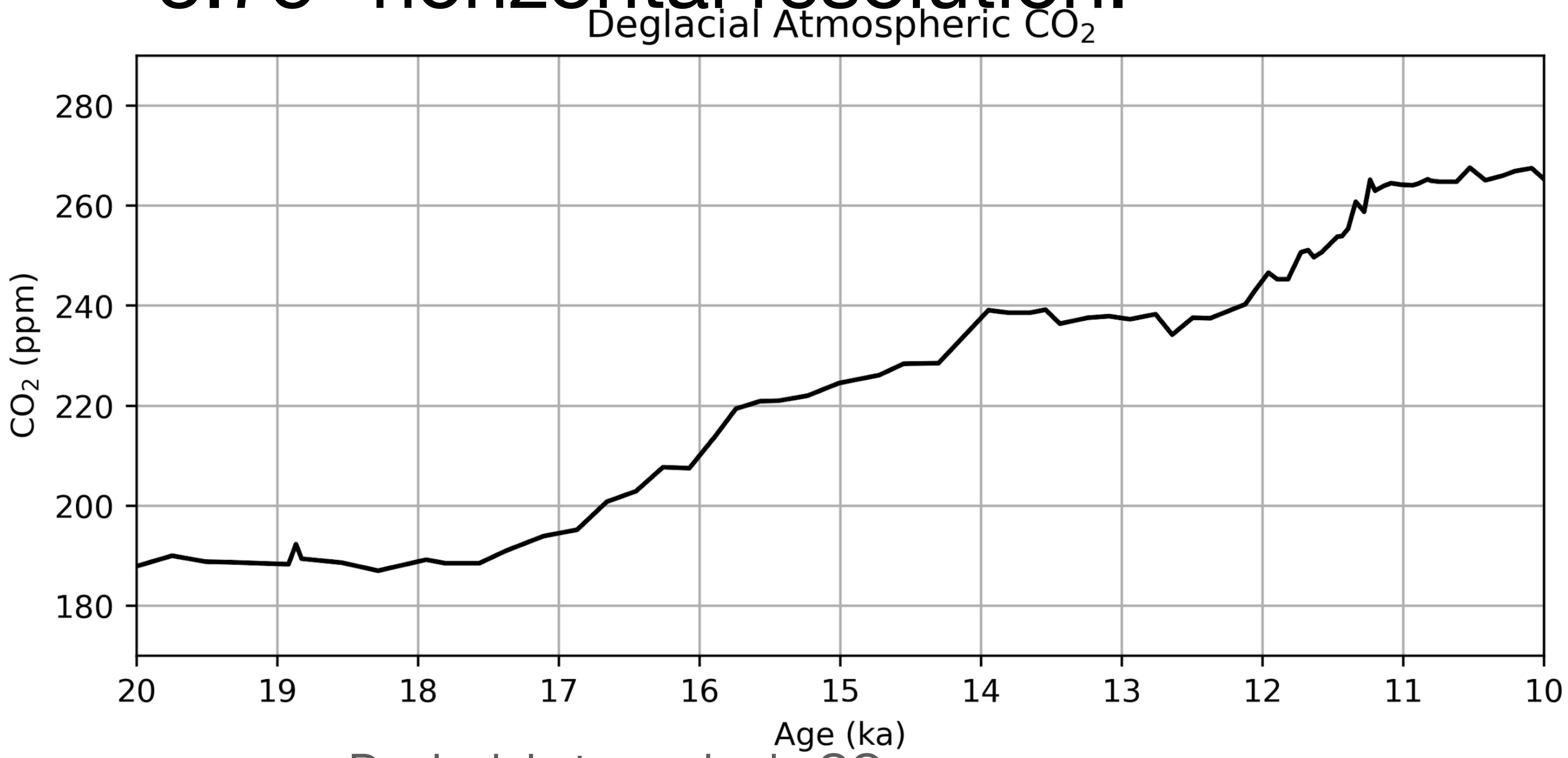


Hydrological cycle over the last deglaciation from Trace21ka. (Lora and Ibarra 2019)

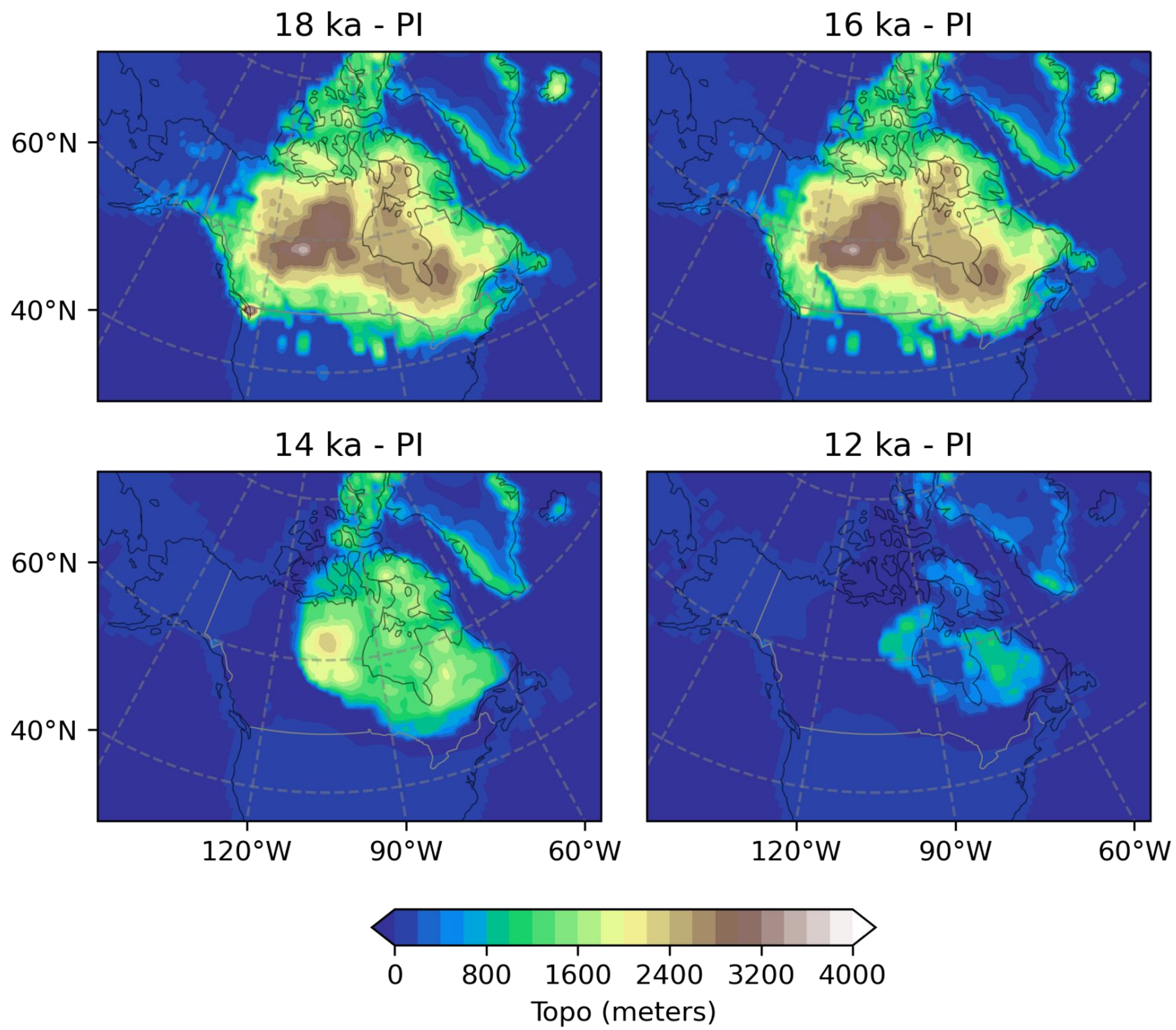
- Few studies have addressed this issue or given a plausible explanation for wetter conditions at 16 ka compared to 20 ka.
- A publicly available modeling study covering the last deglaciation (Trace21ka; Liu et al., 2009) shows near monotonic drying since 20 ka.
- Another study suggested that freshwater forcing from a Heinrich event (HS1) may have played a role (McGee et al. 2018).

iTraCE: a new simulation of the Last Deglaciation

- I use the updated iTraCE simulation, an update of TraCE-21ka.
  (Otto-Bliesner, Brady, Tomas, Liu, and He)
  - iTraCE: iCESM 1.3, iCAM5, ICE-6G, ~2° horizontal resolution (+ isotopes).
  - TraCE-21ka: CCSM3, CAM3, ICE-5G, 3.75° horizontal resolution.



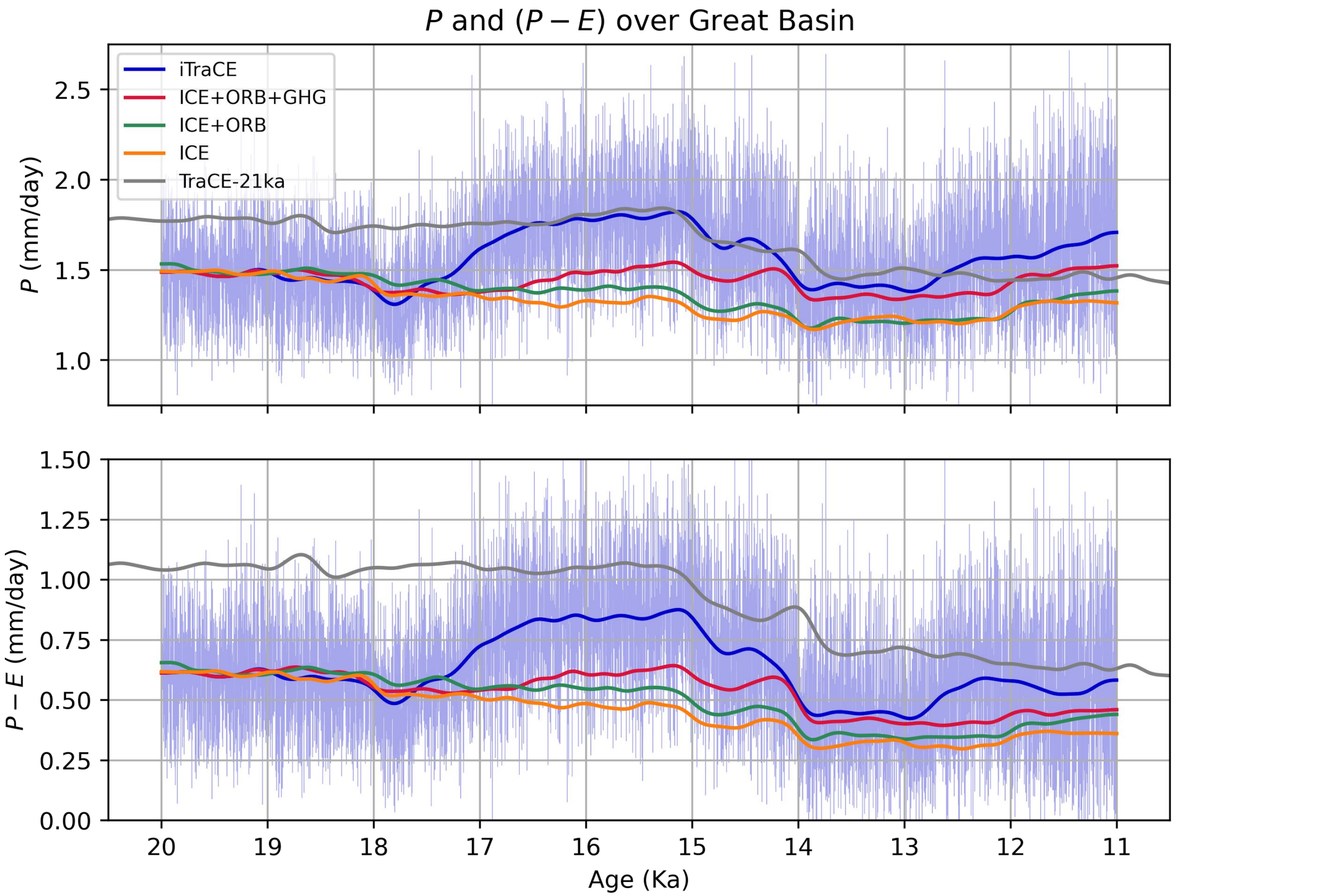
Deglacial atmospheric CO_2
(Indermuehle et al. 1999, Monnin et al. 2001)



Intermediate ice sheet topography
(ICE-6G; Peltier et al. 2015)

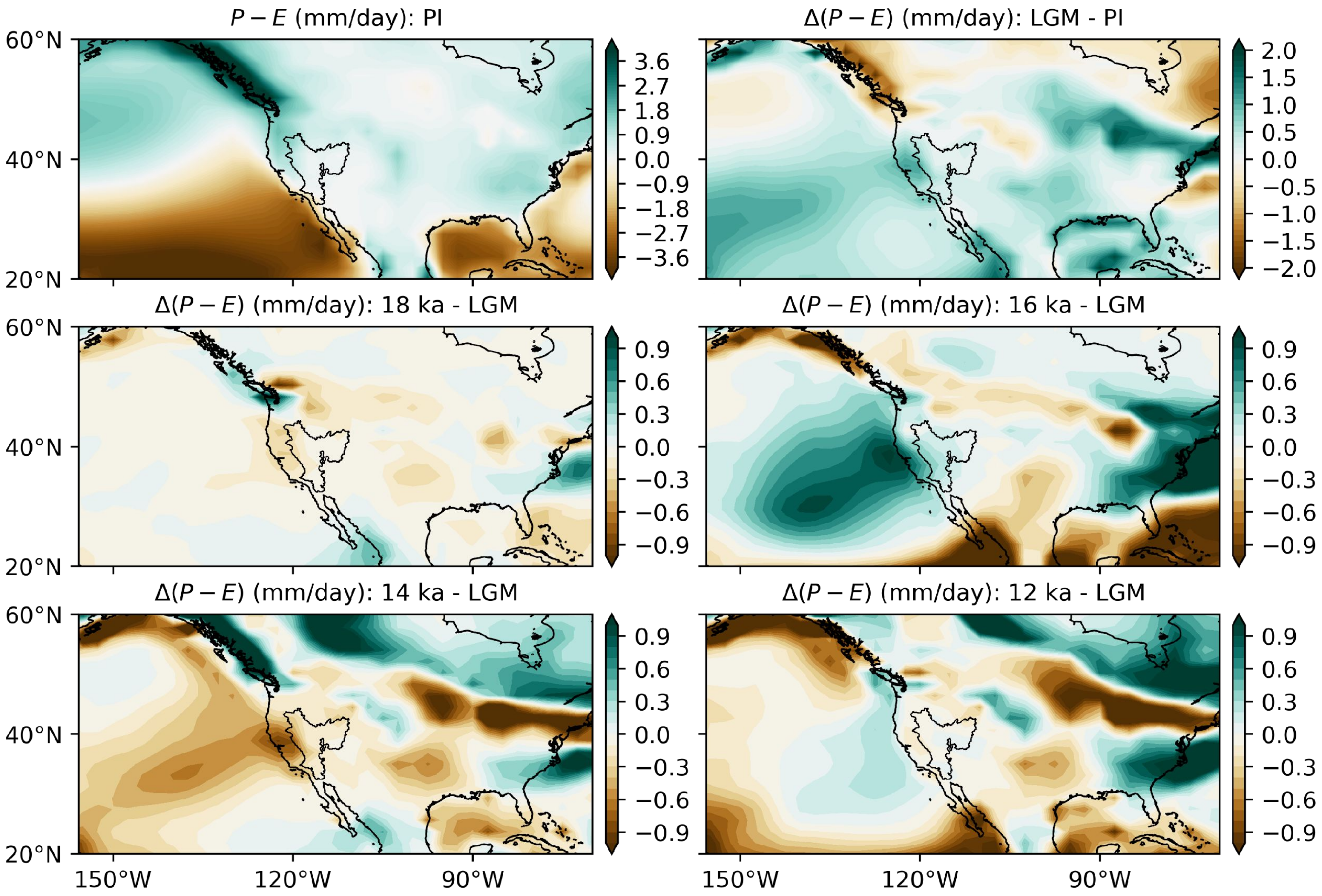
Hydrological cycle over the Western US

- In contrast to prior studies, I find a robust peak in Western US rainfall over the Great Basin at around 16 ka.
- Annual mean P is 20% and *P-E* is 39% higher at 16 ka compared to 20 ka.
- Compares much more favorably to geological evidence.



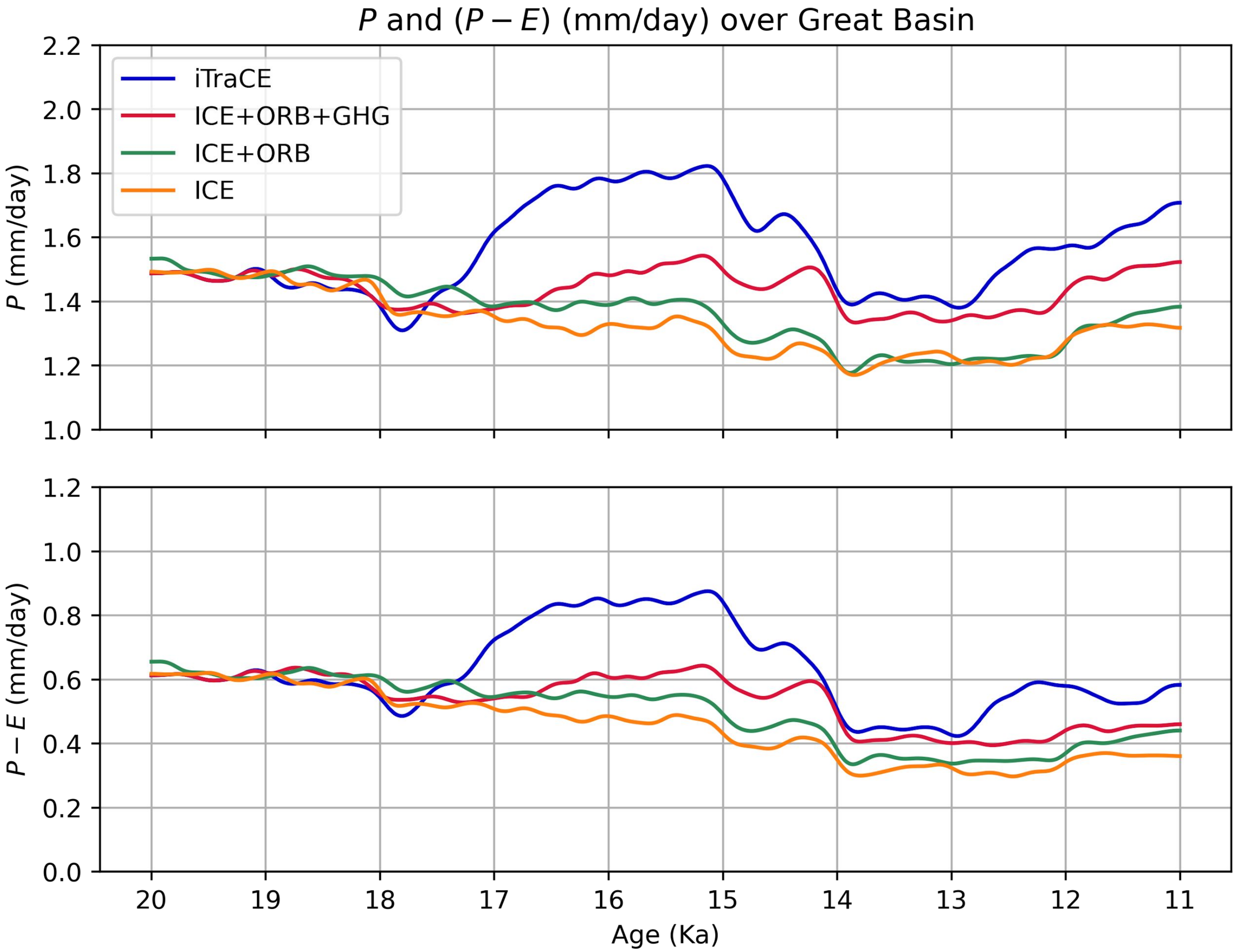
Hydrological cycle over the Western US

- Wetter-than preindustrial conditions at 20 ka.
- iTraCE shows a robust increase in P-E over the Southwestern US post-LGM (~16ka).
- By 14 ka conditions over the Great Basin are drier than 20 ka and transitioning to modern arid conditions.



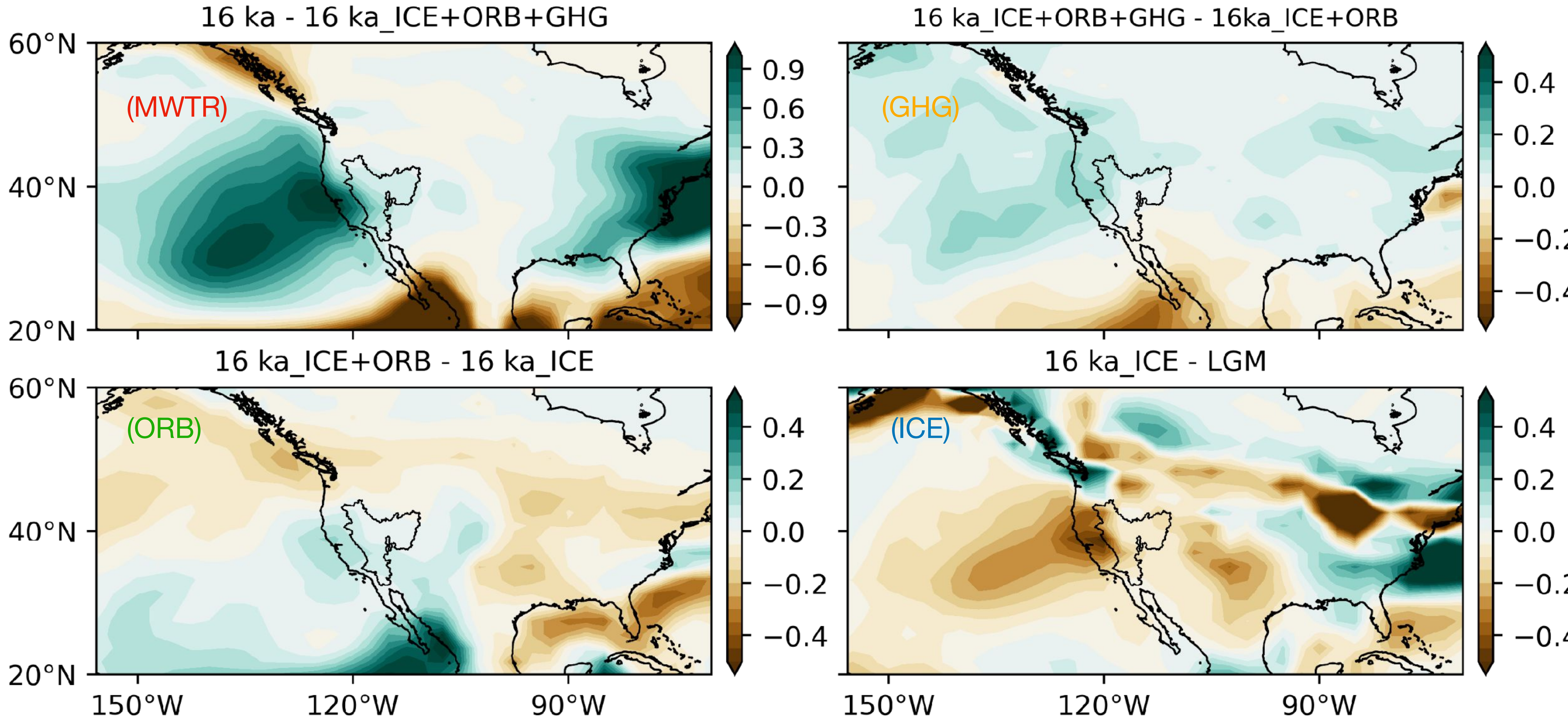
Role of Meltwater, Orbit, and CO_2

- iTraCE provides "stacked forcing" experiments.
- Meltwater forcing plays a principal role, increasing P-E by ~0.2 mm/day (consistent with McGee et al. 2018).
- Changing orbit and CO_2 also play a non-negligible role, increasing P-E by ~0.15 mm/day.
- Meltwater flux alone cannot explain lake expansions without changes in orbit and CO_2.



Decomposing P-E in stacked forcing experiments

- We decompose the difference between 16 ka and 20 ka *P-E* into individual forcing agents.



(SUM) 16 ka - LGM = (16 ka - 16 ka_ice+orb+ghg) (MWTR)

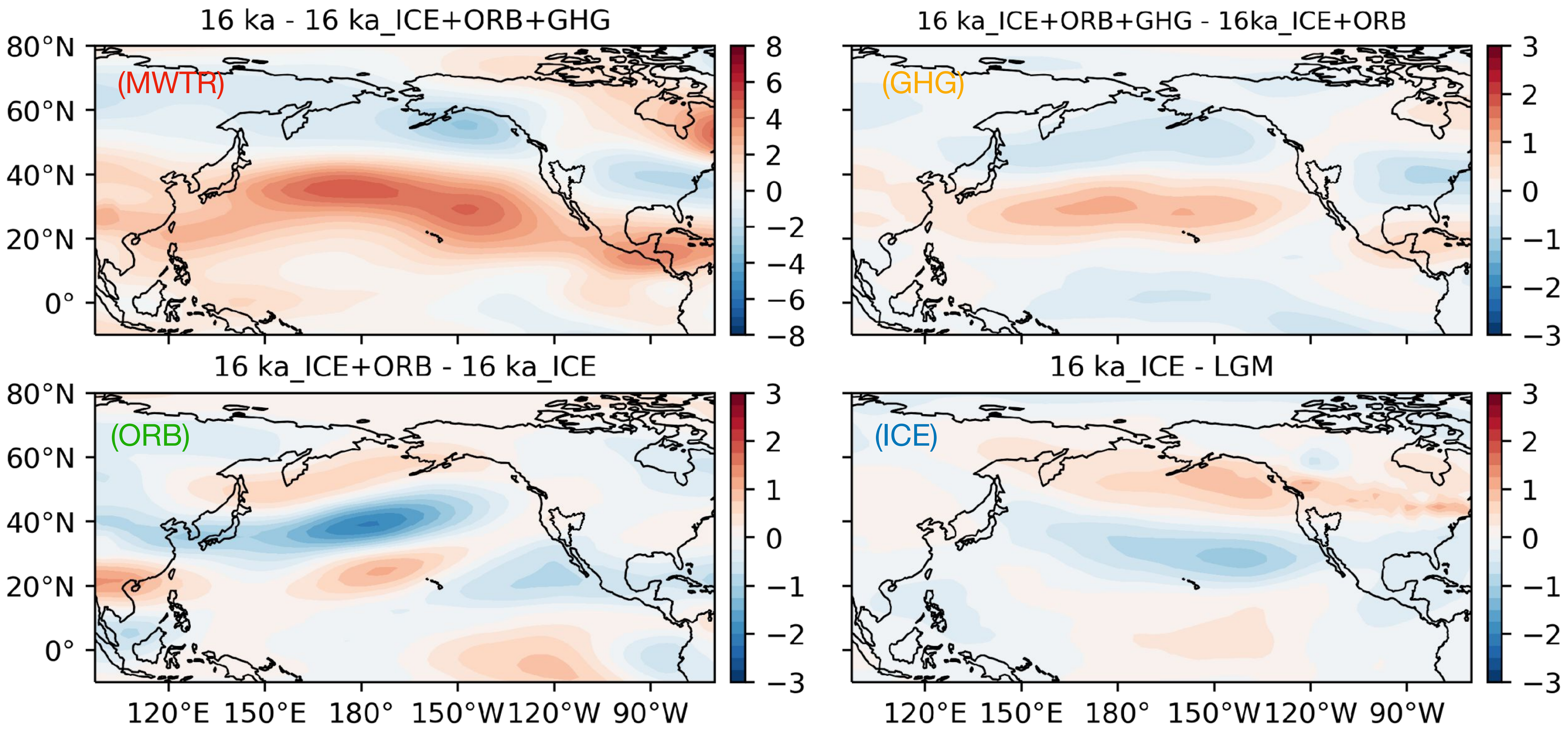
\+ (16 ka_ice+orb+ghg - 16 ka_ice+orb) (GHG)

\+ (16 ka_ice+orb - 16 ka_ice) (ORB)

\+ (16 ka_ice - LGM) (ICE)

Mechanisms for 16 ka peak

- Now we do the same for the atmospheric circulation (U500).
- Both greenhouse gasses and changing insolation contribute to southward shift of North Pacific Jet.



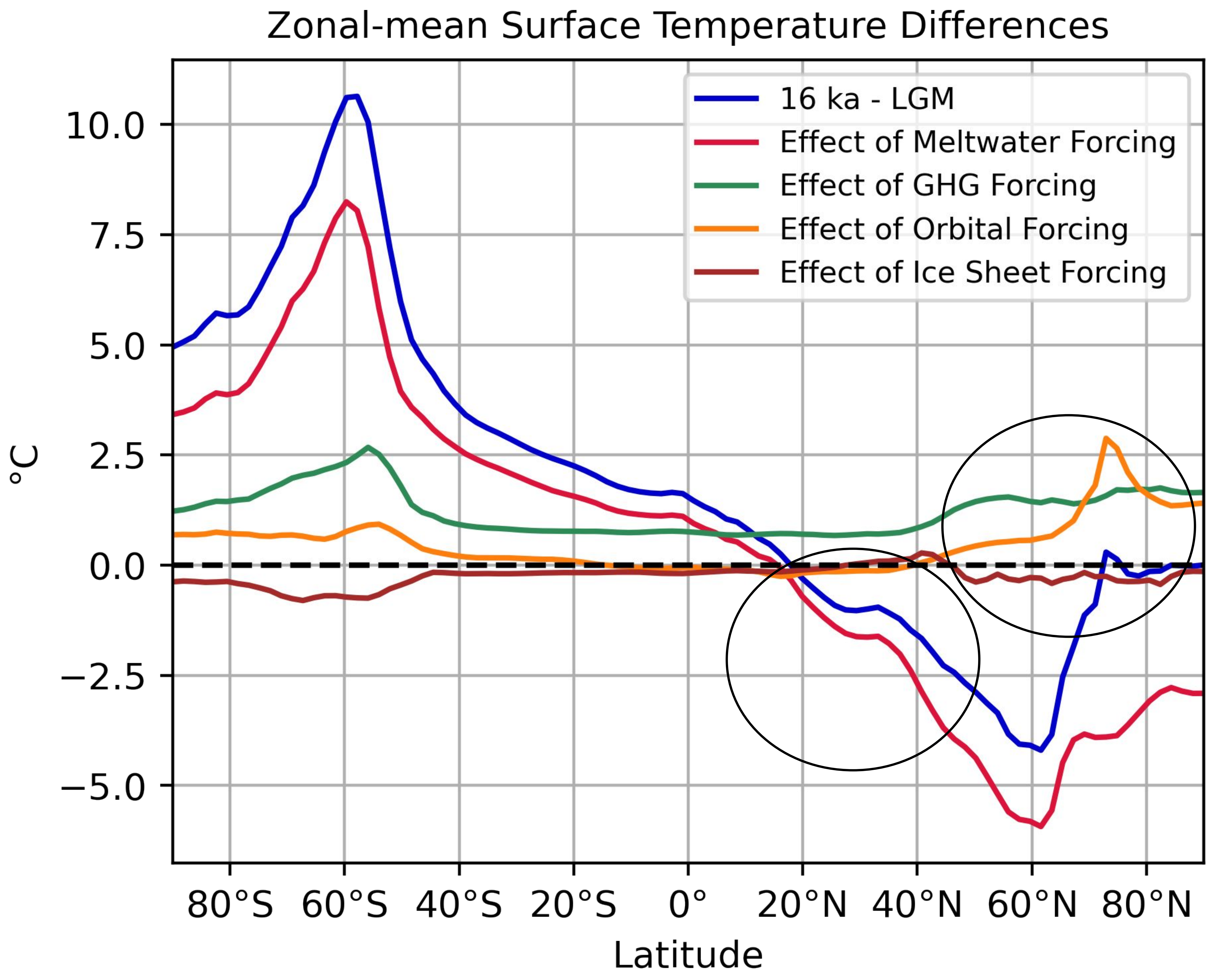
(SUM) 16 ka - LGM = (16 ka - 16 ka_ice+orb+ghg) (MWTR)

\+ (16 ka_ice+orb+ghg - 16 ka_ice+orb) (GHG)

\+ (16 ka_ice+orb - 16 ka_ice) (ORB)

\+ (16 ka_ice - LGM) (ICE)

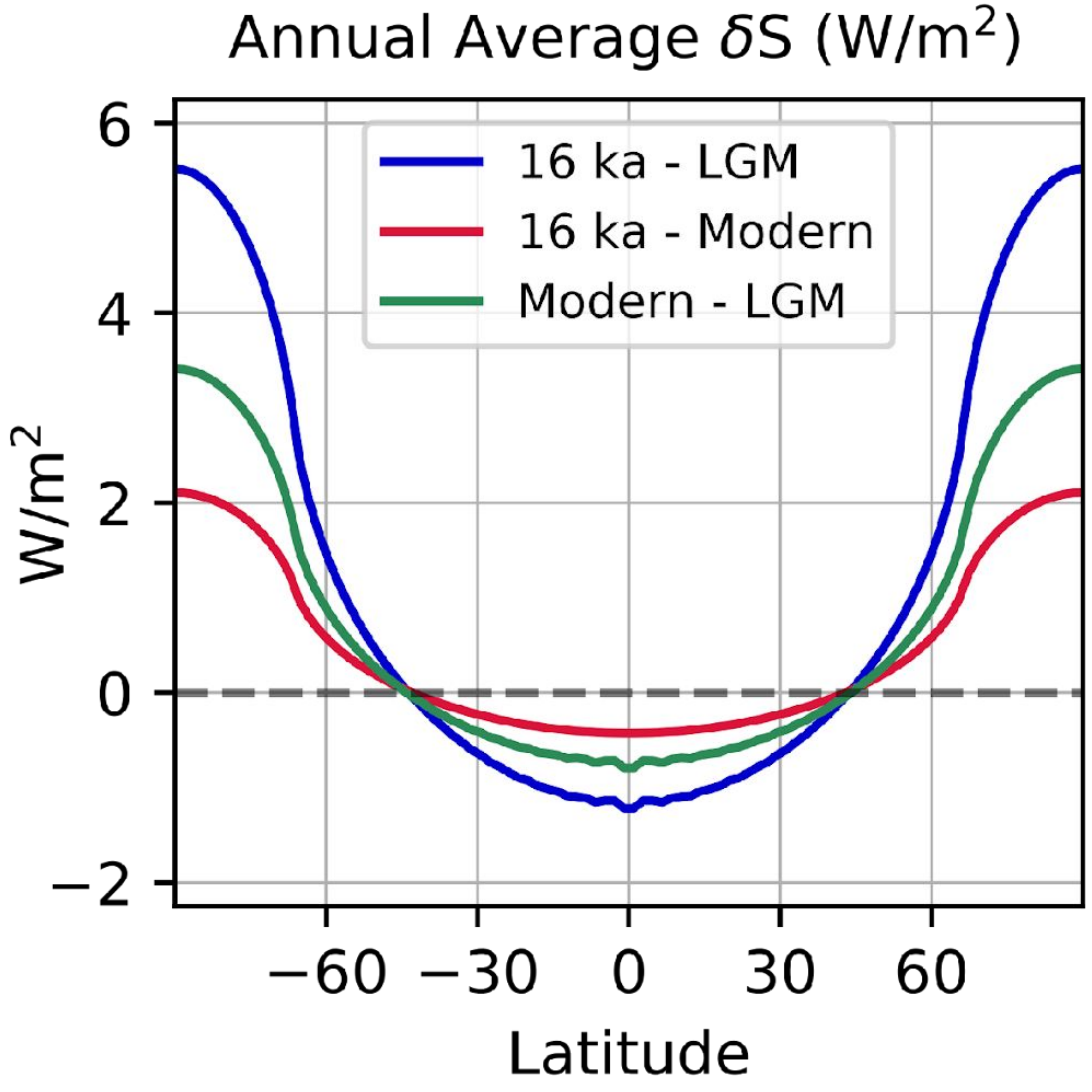
Zonal Mean Surface Temperature



- Meltwater forcing: steepening of temperature gradients in the northern midlatitudes.
- Orbital and GHG forcing: reduced surface temperature gradient on the poleward side of the midlatitude jet.
- Combine to cause a southward-deflection of the North Pacific Jet at 16 ka.

Orbital Configuration

- 16 ka conditions were characterized by higher obliquity compared to LGM.
- This leads to higher insolation north of 45°N, and lower insolation in the midlatitudes.



Annual-mean insolation distributions for modern, LGM, and 16 ka conditions.

Summary

I suggest several changing boundary conditions between LGM and 16 ka conspired to cause the HS1 lake expansions over the western US.

► The presence of the Cordilleran/Laurentide ice sheet lead to a southward-deflected storm track and wet LGM conditions.

► Polar-amplified warming caused by increasing obliquity and CO_2 maintained a southward shifted jet despite ice-sheet retreat.

►Meltwater forcing from HS1 lead to a southward-shifted ITCZ and further shift/strengthening of the North Pacific jet, contributing to expansion of Great Basin lakes.

► After ~15 ka, the ice sheet retreated rapidly and the storm track shifted poleward, leading to the onset of arid conditions.

Thank you for your attention

Reference:

Fu, Minmin. "Revisiting western United States hydroclimate during the last deglaciation." *Geophysical Research Letters* 50.3 (2023): e2022GL101997.