Atmospheric Rivers and the Changing Climate of Western North America Since the Last Glacial Maximum

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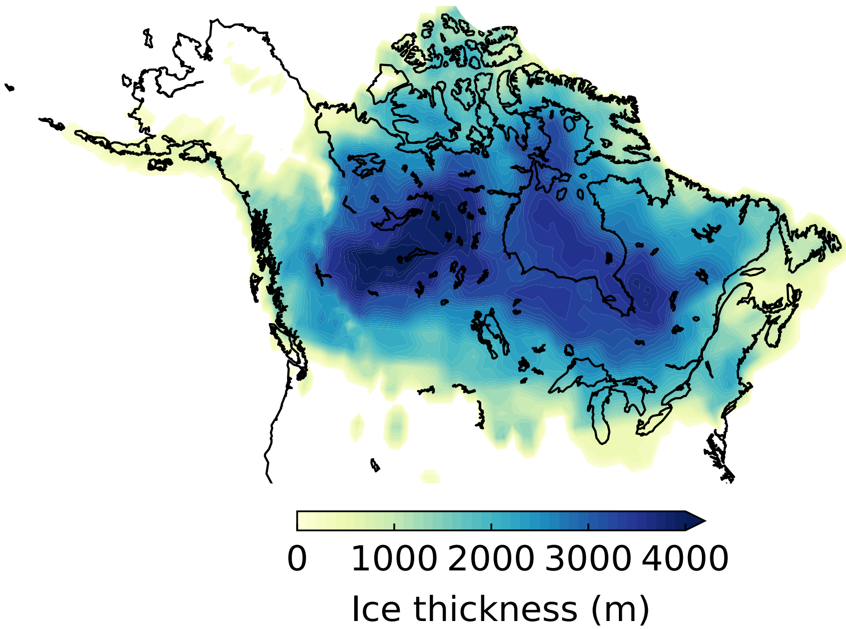
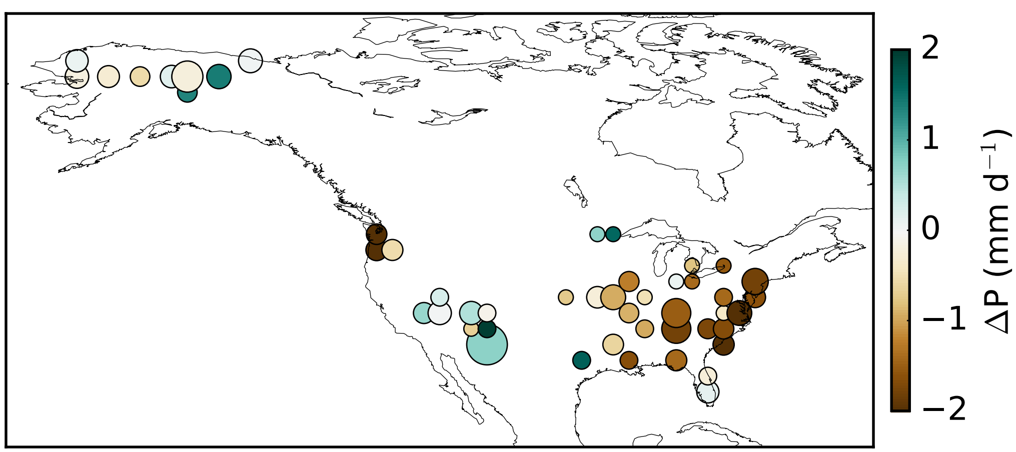
Last Glacial Maximum:

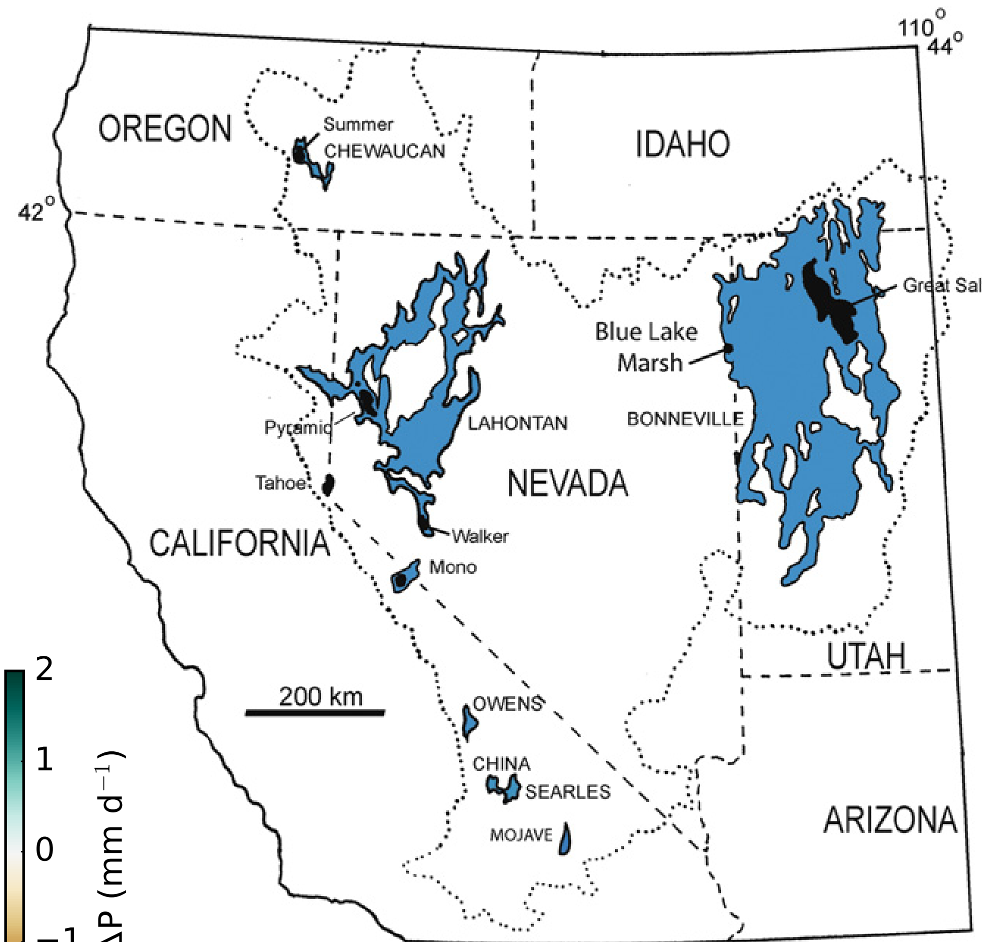
- ~21 ka
- ~185 ppm CO_2
- ~120 m lower sea level
- Dry or wet?

Western North America Is Dry Today but Was Wet During the Last Glacial Maximum



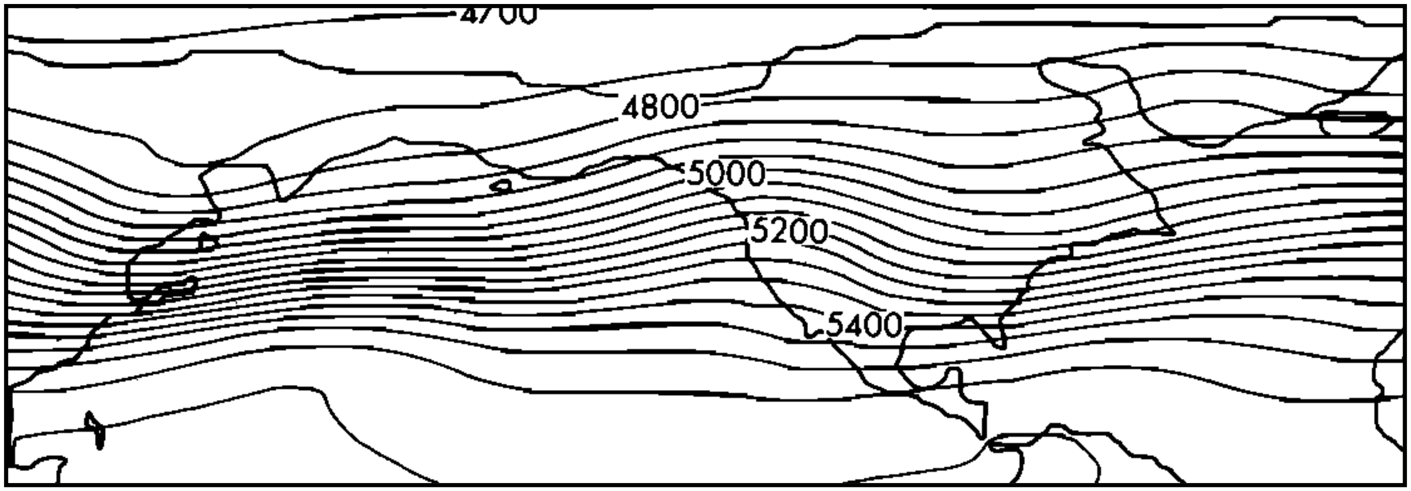


Bartlein et al. (2011)

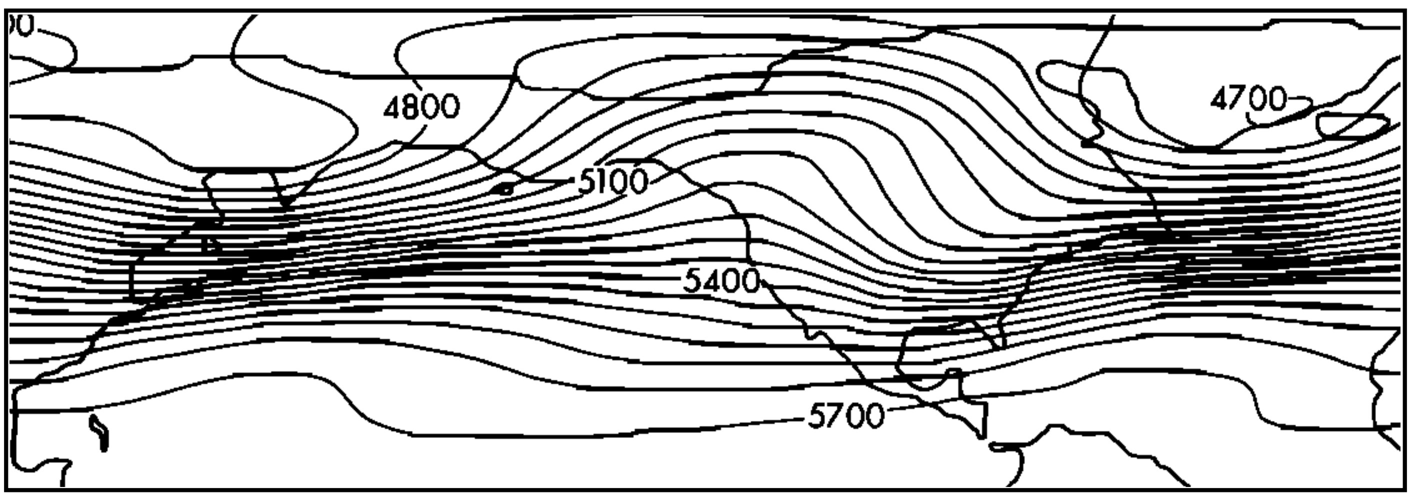


Benson et al. (2011)

This Wetness Has Been Interpreted as a Shift of the North Pacific Mid-Latitude Jet and Storm Track



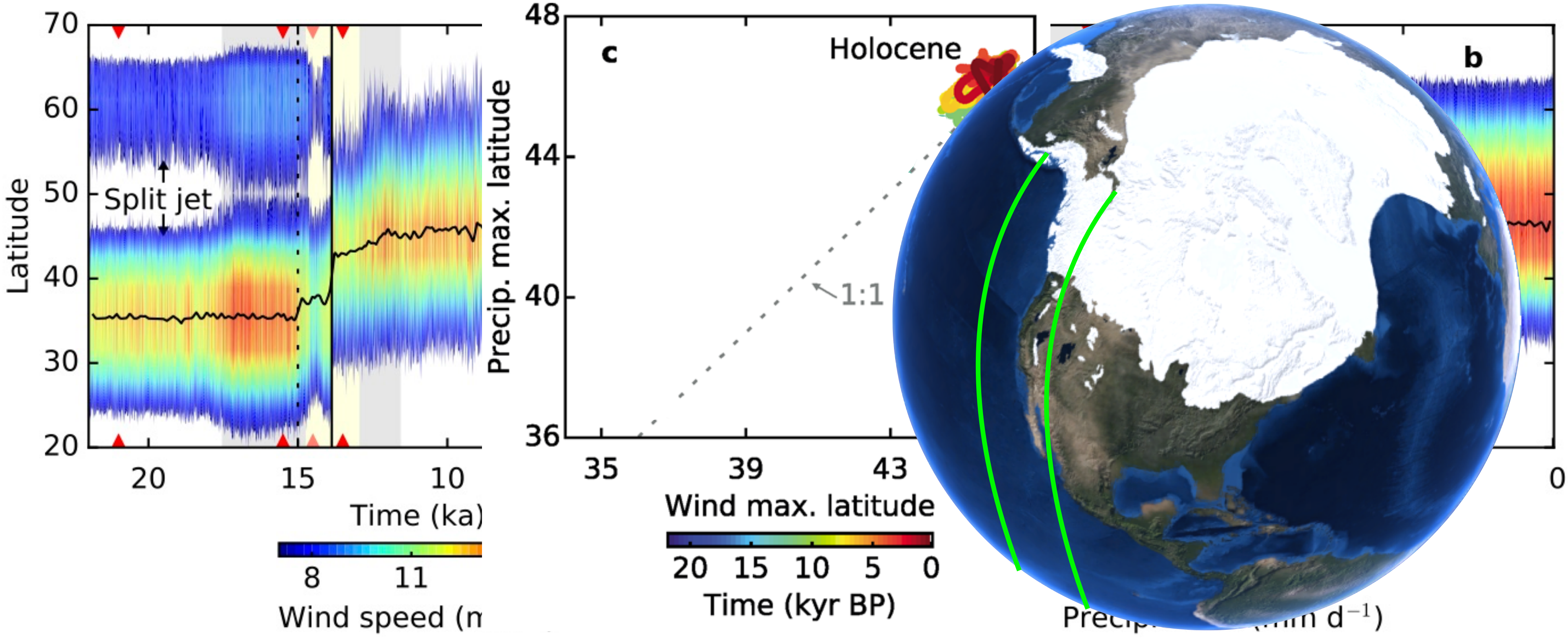
DJF 515 mbar Geopotential Height (m)



Last Glacial Maximum

Manabe & Broccoli (1985)

But Do the Positions of Precipitation and the Climatological Jet Always Coincide?



Lora et al. (2016), GRL

New Hypotheses for "Pluvial" Conditions in Western North America

Out of the Tropics: The Pacific, Great Basin Lakes, and Late Pleistocene Water Cycle in the Western United States

Mitchell Lyle,[1*] Linda Heusser,[2] Christina Ravelo,[3] Masanobu Yamamoto,[4] John Barron,[5] Noah S. Diffenbaugh,[6] Timothy Herbert,[7] Dyke Andreasen[3]

SCIENCE VOL 337 28 SEPTEMBER 2012

→ **Intensified NA Monsoon**

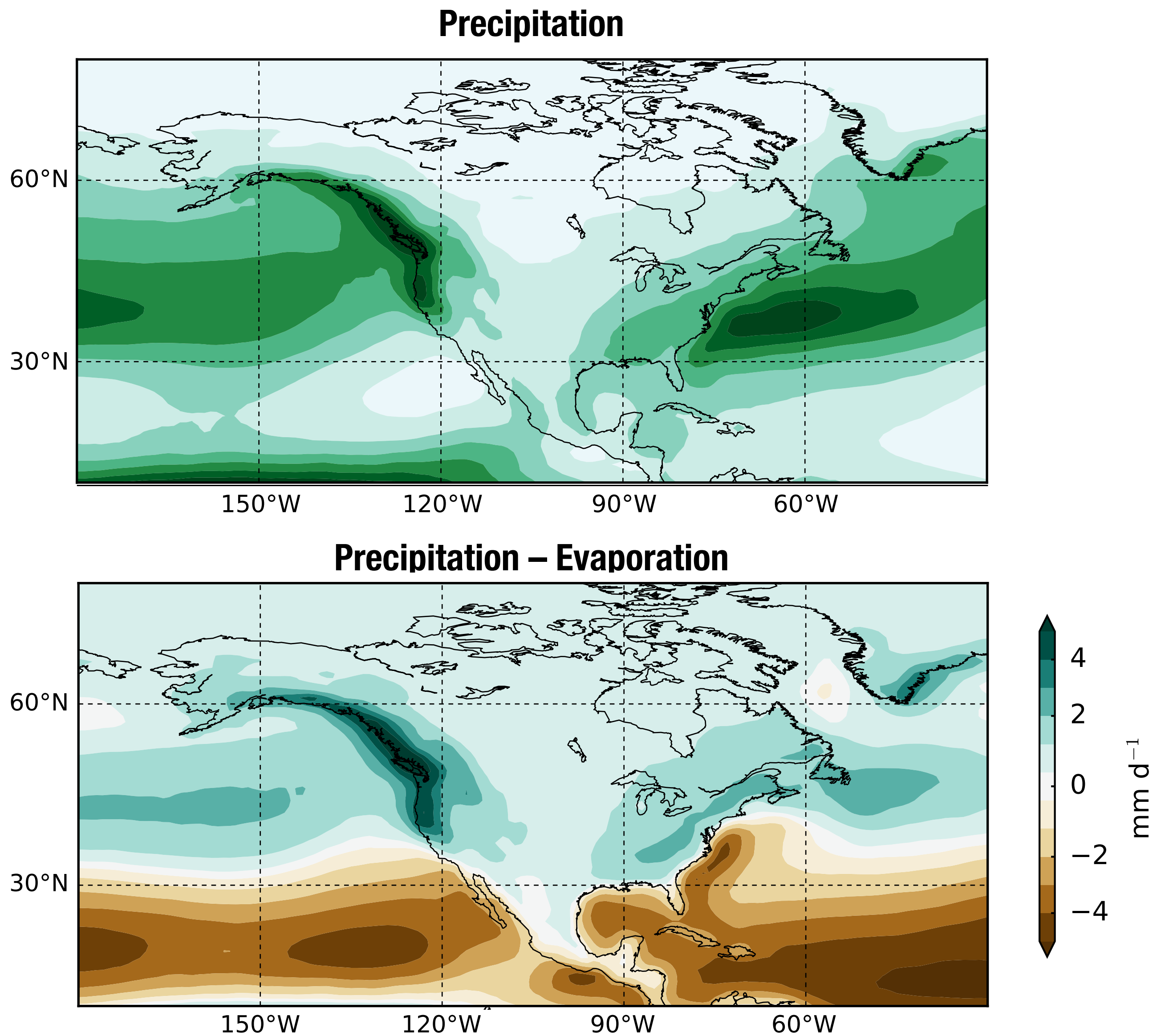
Steering of westerly storms over western North America at the Last Glacial Maximum

Jessica L. Oster[1*], Daniel E. Ibarra[2,3], Matthew J. Winnick[2] and Katharine Maher[3]

NATURE GEOSCIENCE | VOL 8 | MARCH 2015

→ **Northwesterly Storm Track**

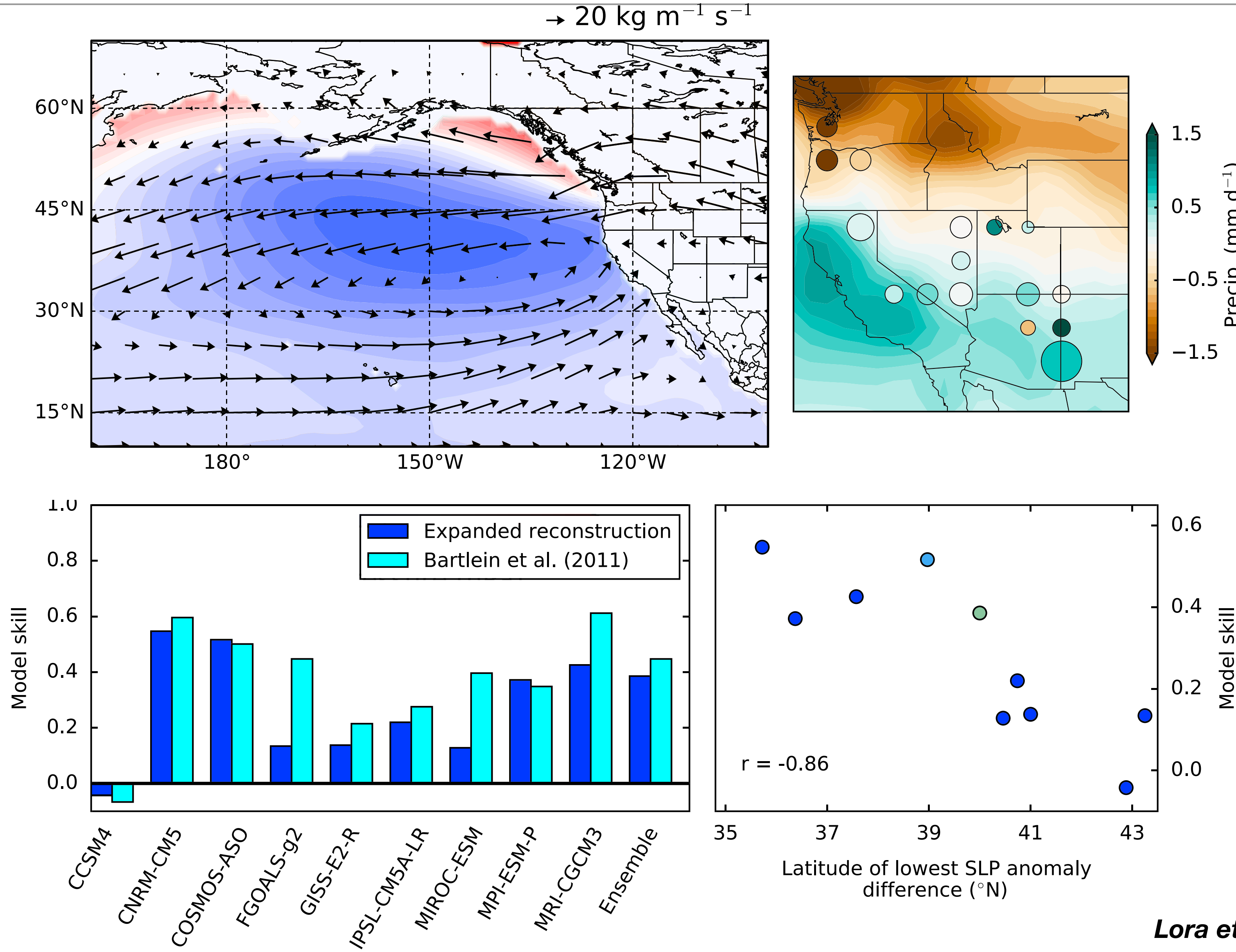
Moisture Budget is Dominated by Wintertime Precipitation and (Little) Evaporation



Winter half-year P and E from 9 CMIP5/PMIP3 model ensemble mean

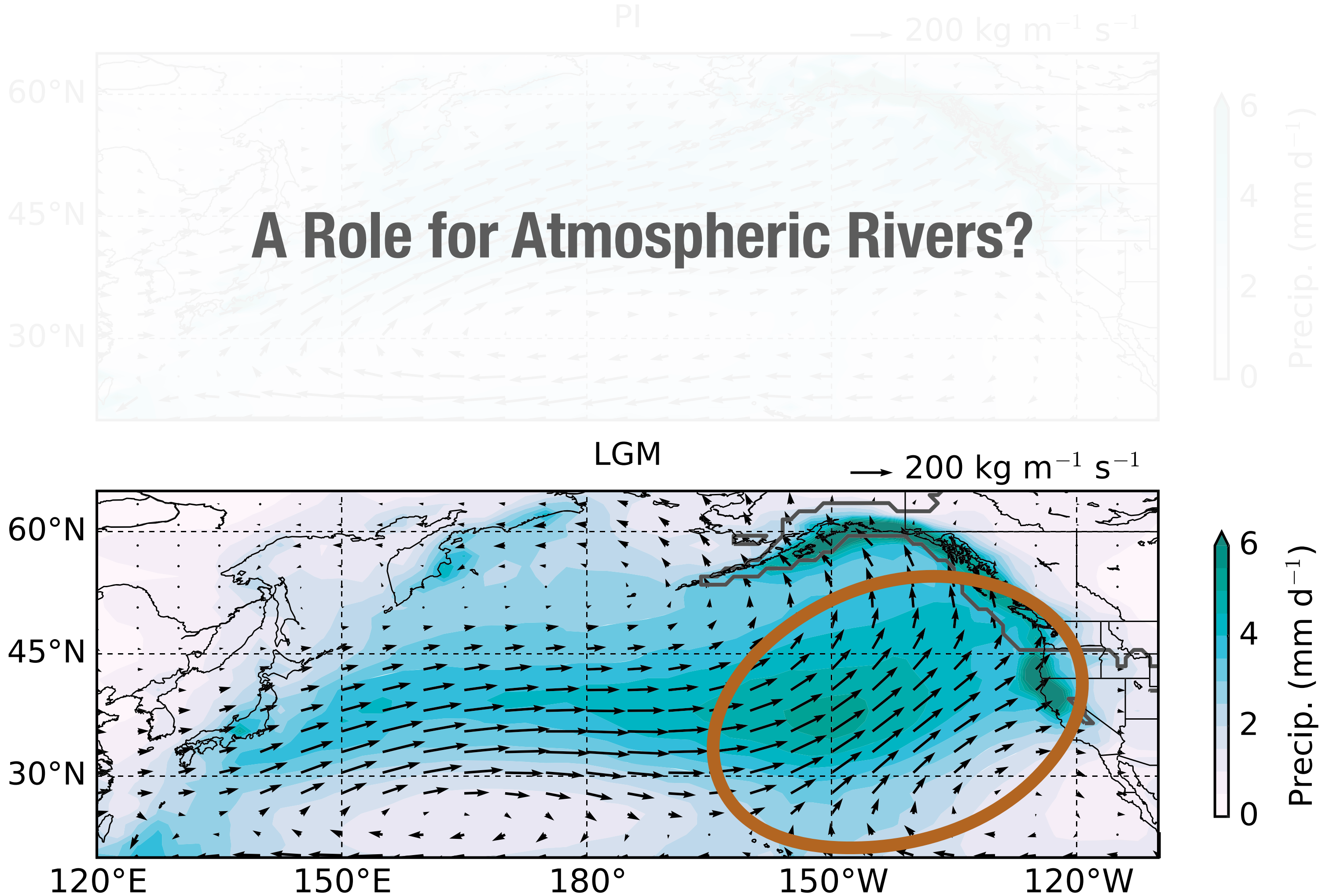
Lora (2018), J. Climate

Terrestrial Hydroclimate Proxies Support Substantial Southeastward Shifts in Mean Moisture Transport



Lora et al. (2017), GRL

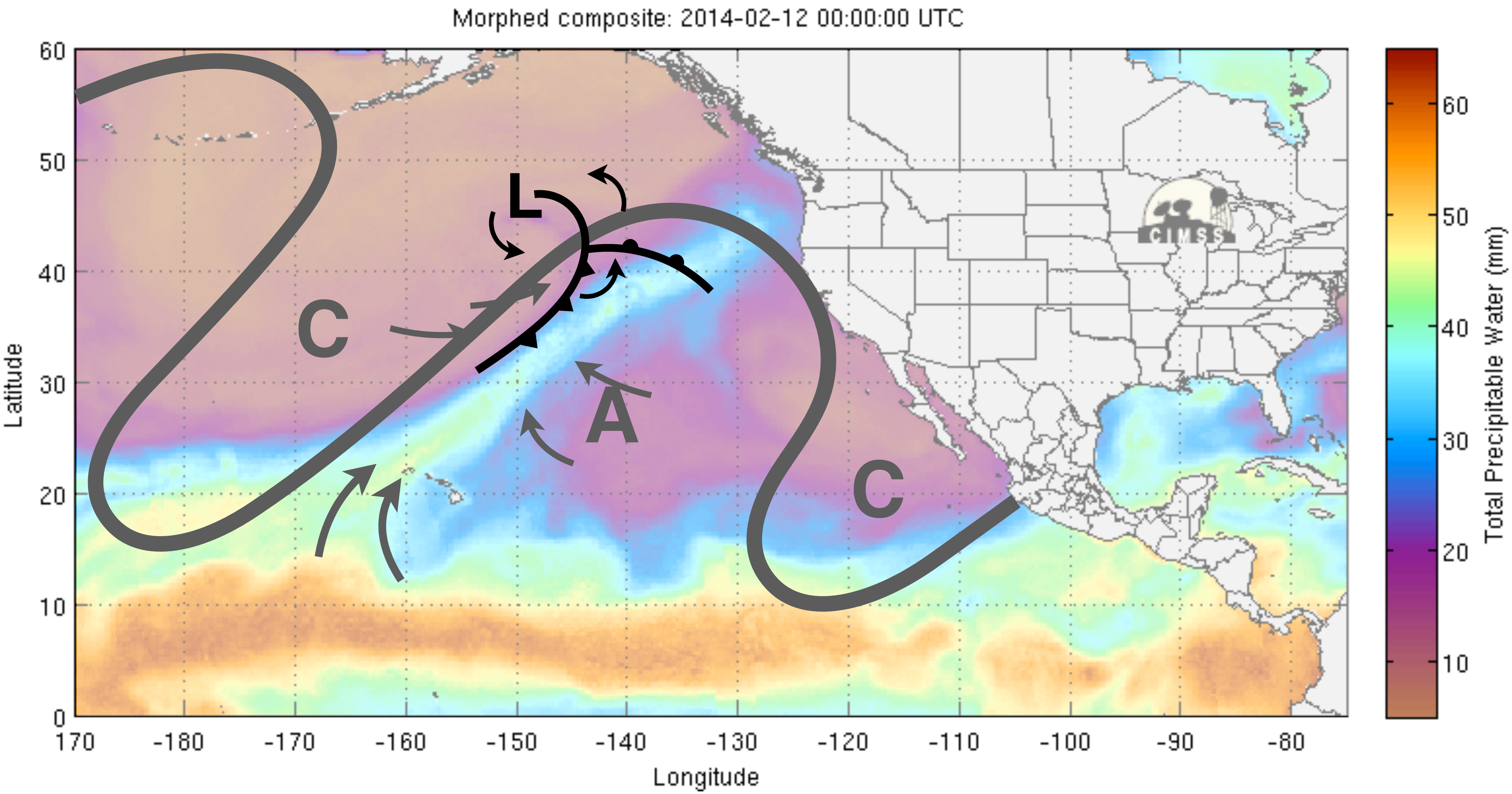
Moisture Transport Increased in the Pineapple Express Region



Winter half-year moisture transport, LMDZ simulations

Lora et al. (2017), GRL

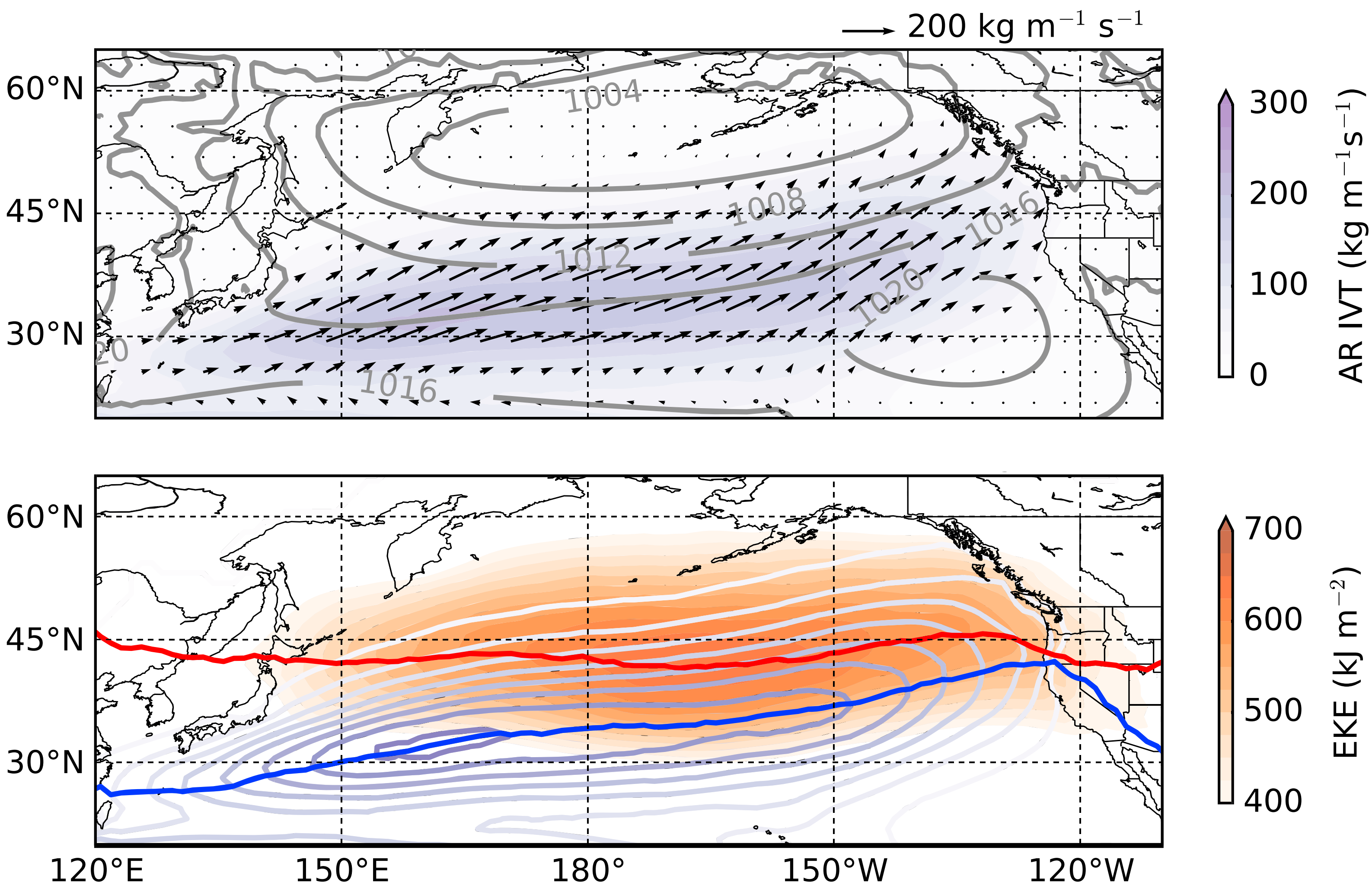
North Pacific Atmospheric Rivers Are a Key Part of the Hydroclimate of Western North America



MIMIC-TPW Satellite Product

CIMSS/U. Wisconsin, Madison

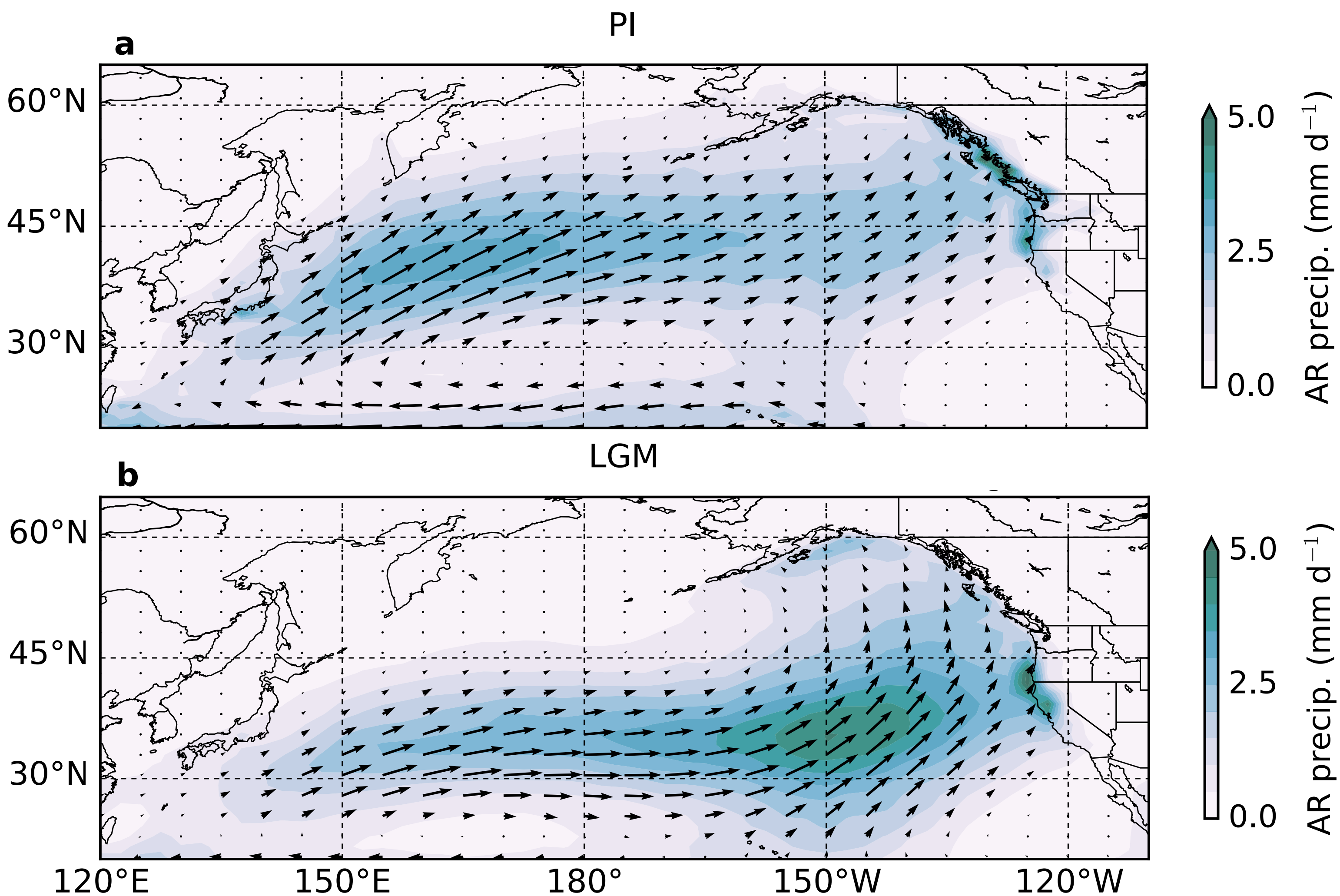
Atmospheric Rivers Transport Moisture into Continent and Partly Reflect Seasonal Surface Pressure Systems



30 years of MERRA-2 Reanalysis (winter half-year mean)

Lora et al. (2017), GRL

Atmospheric River Moisture Transport Shifted Southeast and Intensified at the Last Glacial Maximum…

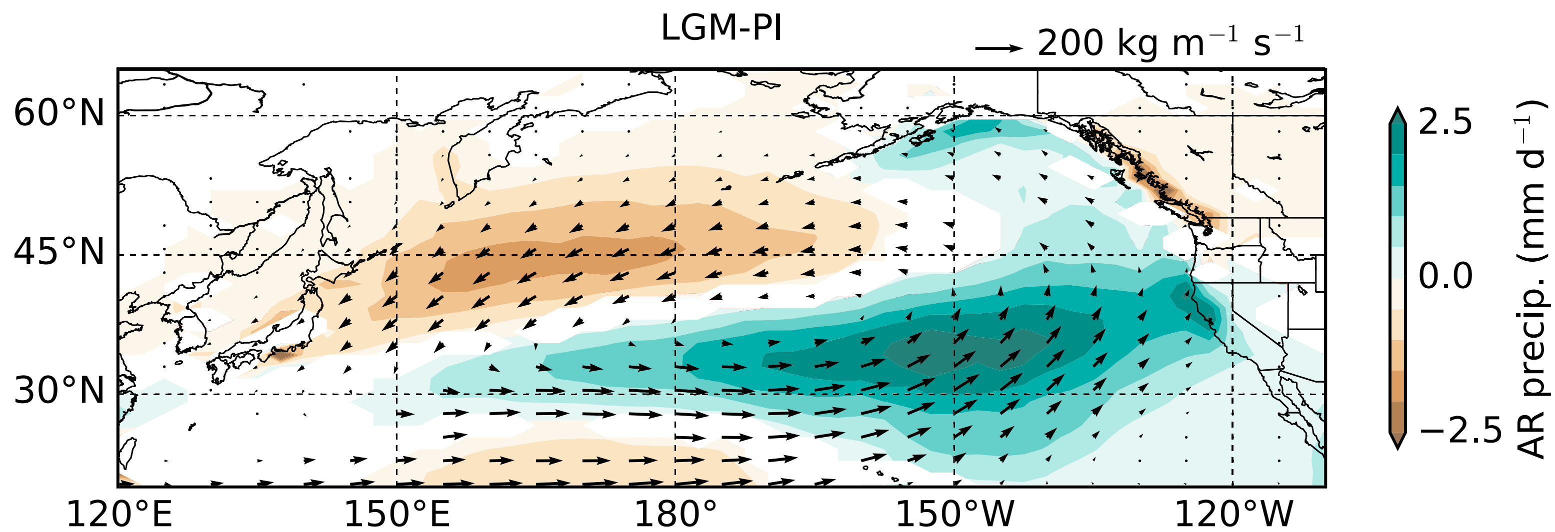


Winter half-year atmospheric river impacts
LMDZ simulations

Lora et al. (2017), GRL

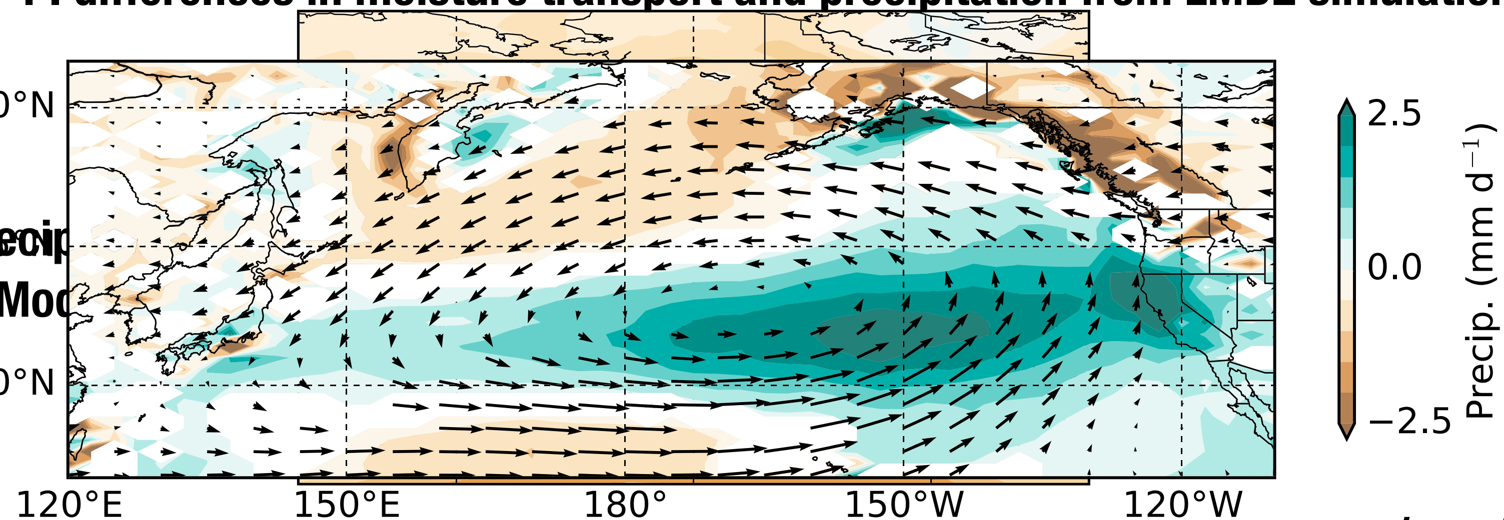
…Causing Precipitation Increases in Pineapple Express Region, and Declines in Pacific Northwest

ARs



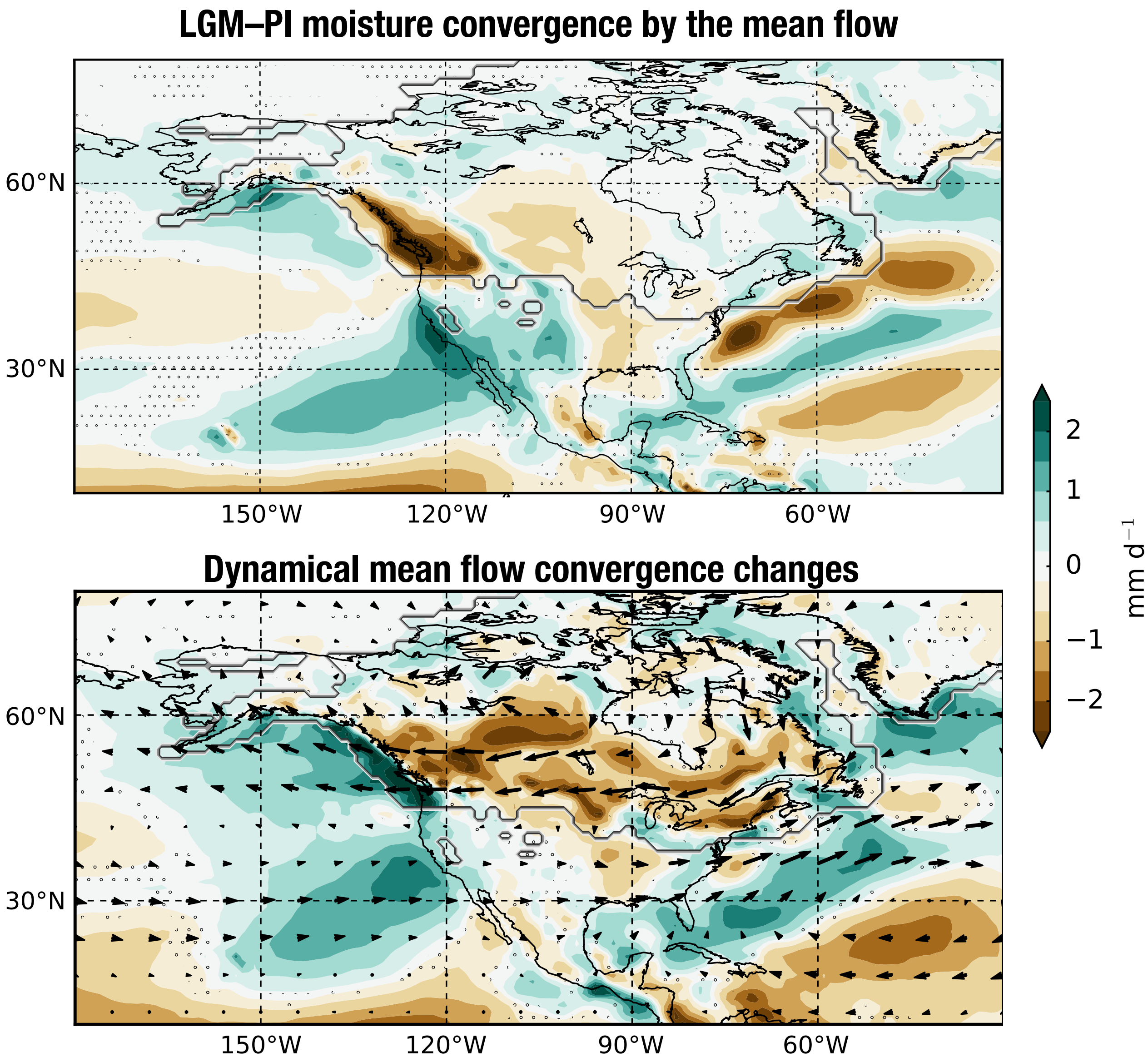
LGM–PI differences in moisture transport and precipitation from LMDZ simulations

LGM–PI precip
Total
PMIP3 Mod



Lora et al. (2017), GRL

Moisture Budget Changes Are Primarily Dynamical Changes to Convergence by the Mean Flow

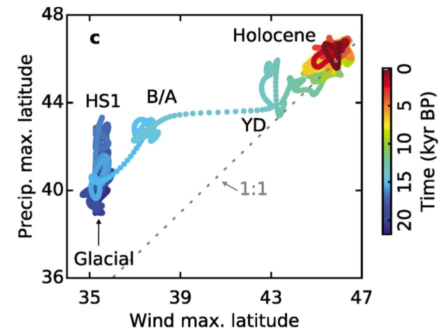


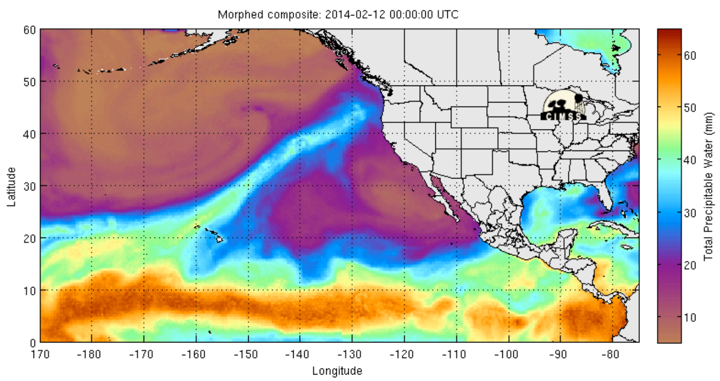
Winter half-year from 9 CMIP5/PMIP3 model ensemble mean

Lora (2018), J. Climate

Summary and Outstanding Questions

- The North American ice sheets split the mid-latitude jet
- But the relationship between the position of the jet and precipitation may have changed the LGM

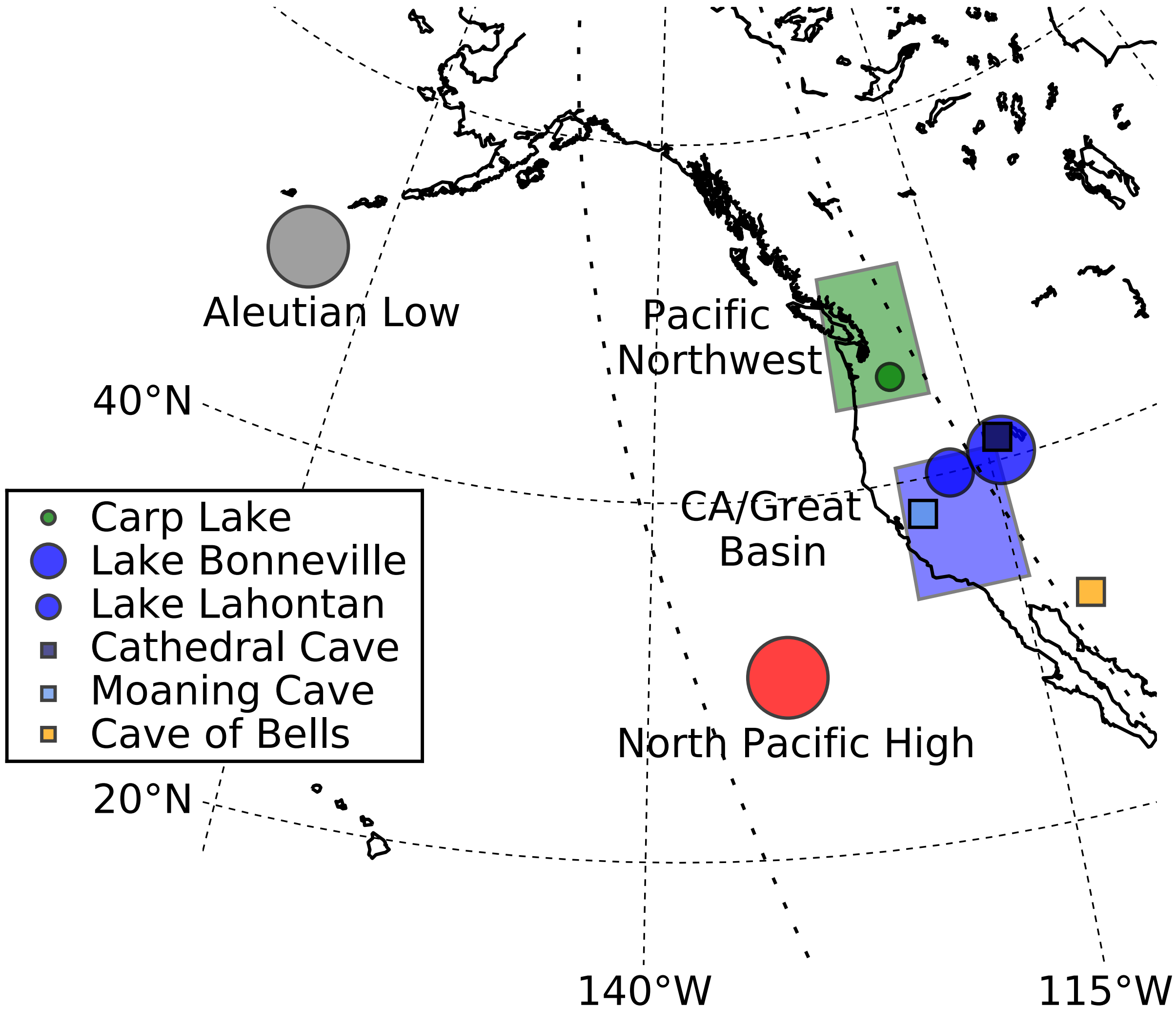




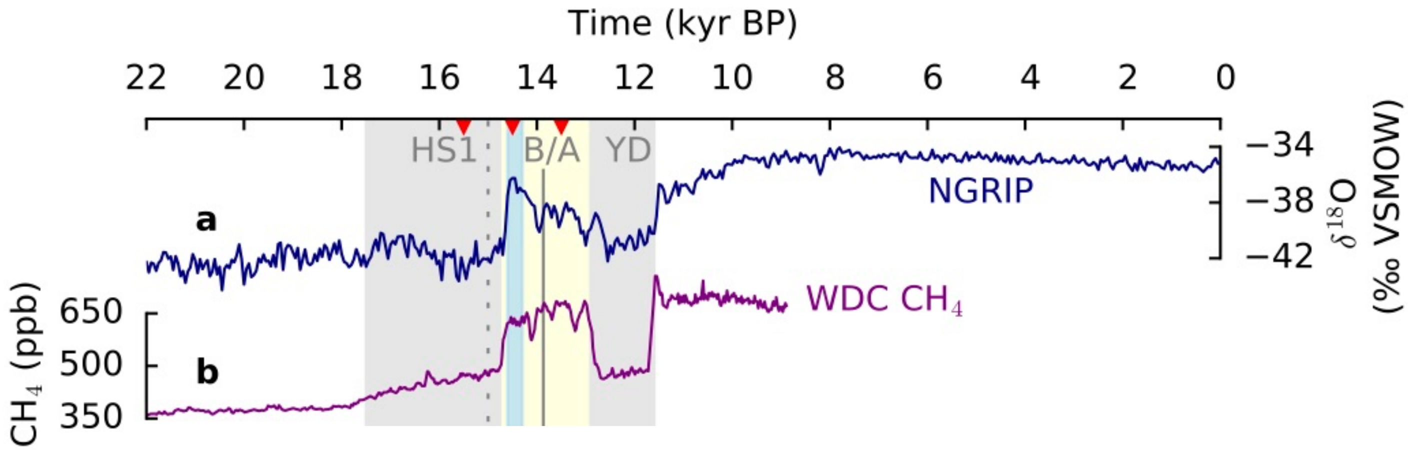
- North Pacific atmospheric river track shifted southeast and intensified at the LGM
- These changes imprint on the mean circulation, and primarily reflect a dynamical mechanism

- How sensitive are these processes to ice sheet changes?
- Did the moisture budget of other mid-latitude regions change since the LGM?
- What was the moisture budget/atmospheric river behavior during other past climates?
- **Ongoing and Future Work:** ARTMIP, CMIP6/PMIP4

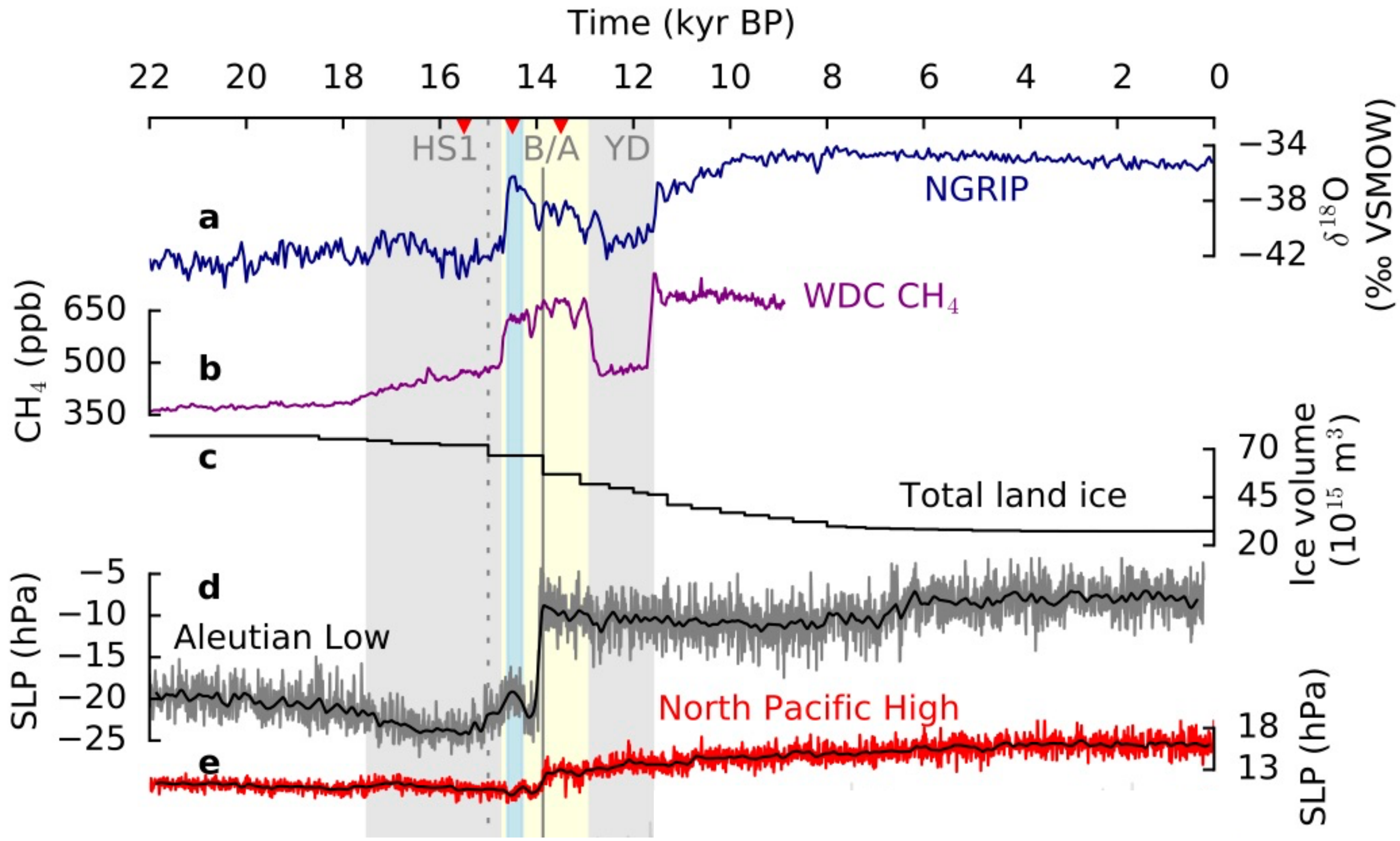
Model-Proxy Comparison



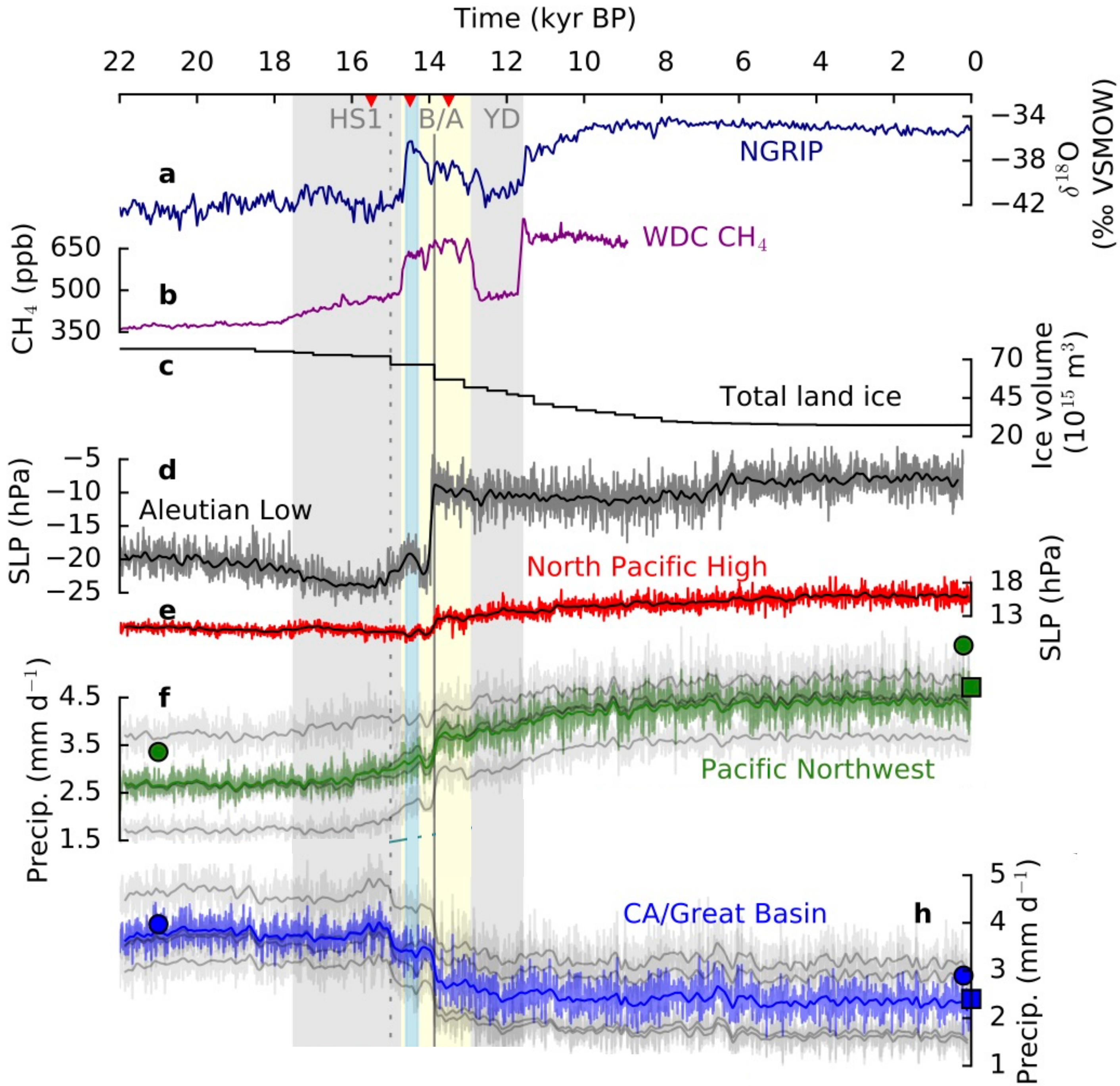
Lora et al. (2016)



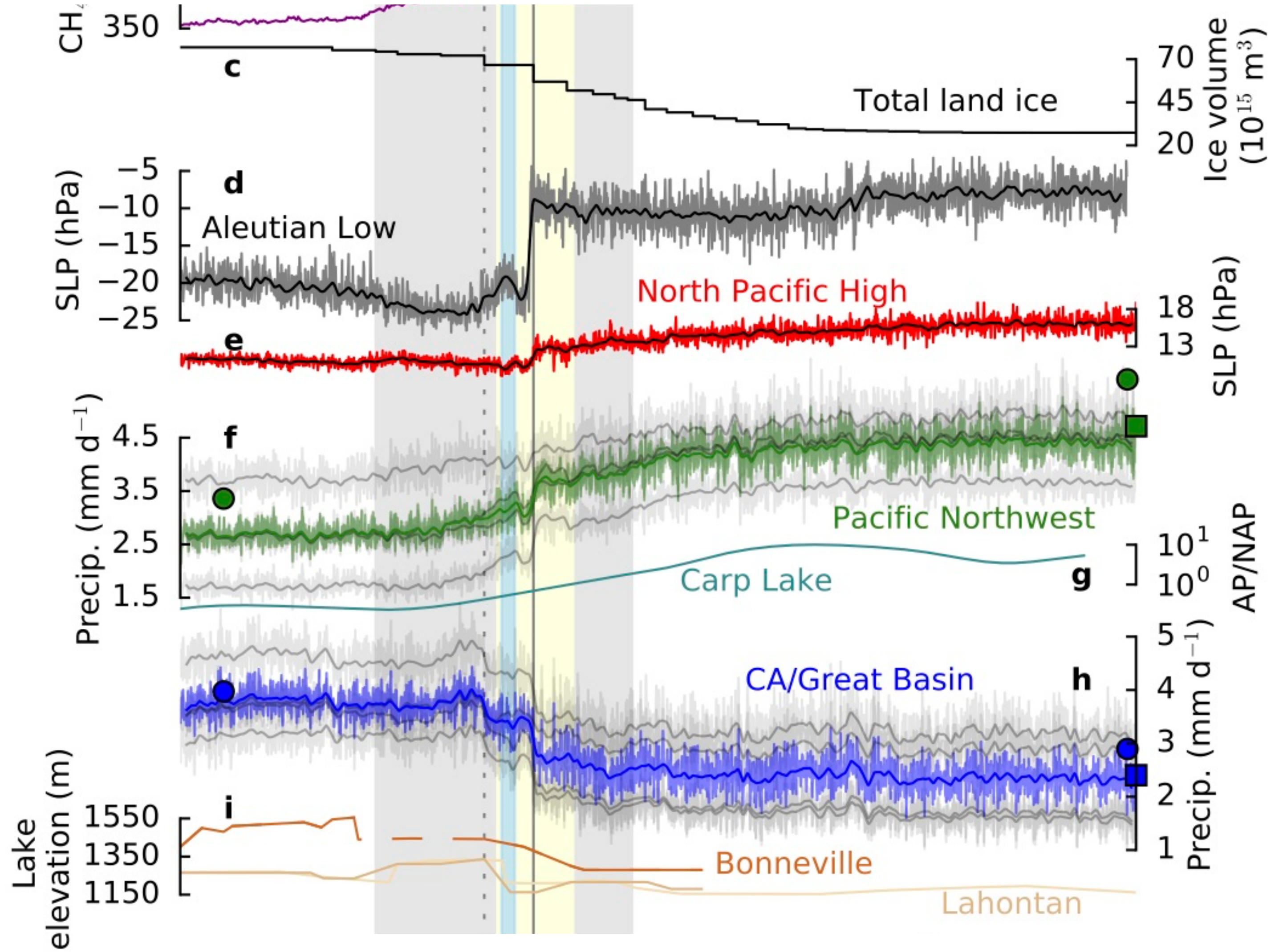
Lora et al. (2016)



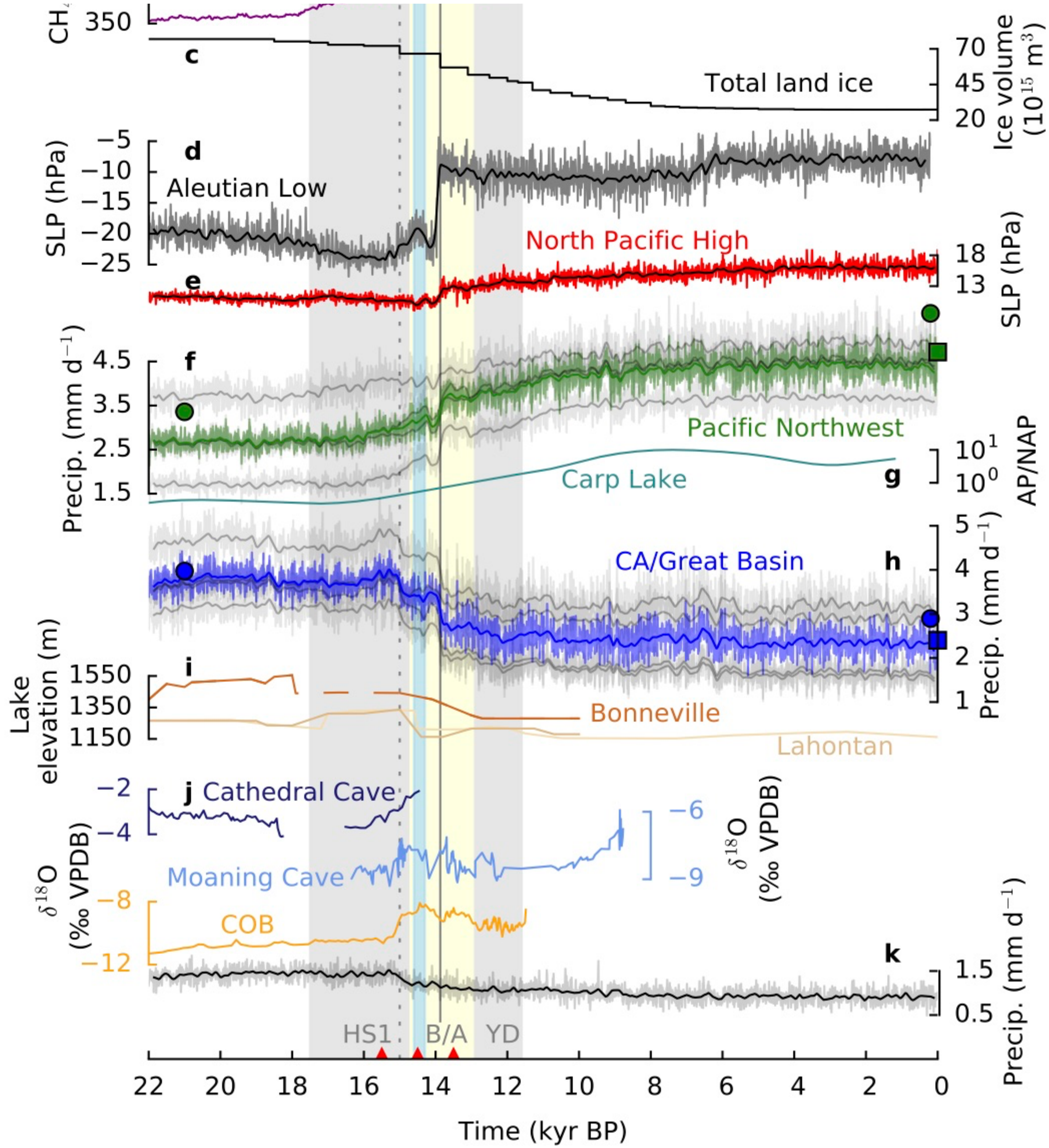
Lora et al. (2016)



Lora et al. (2016)

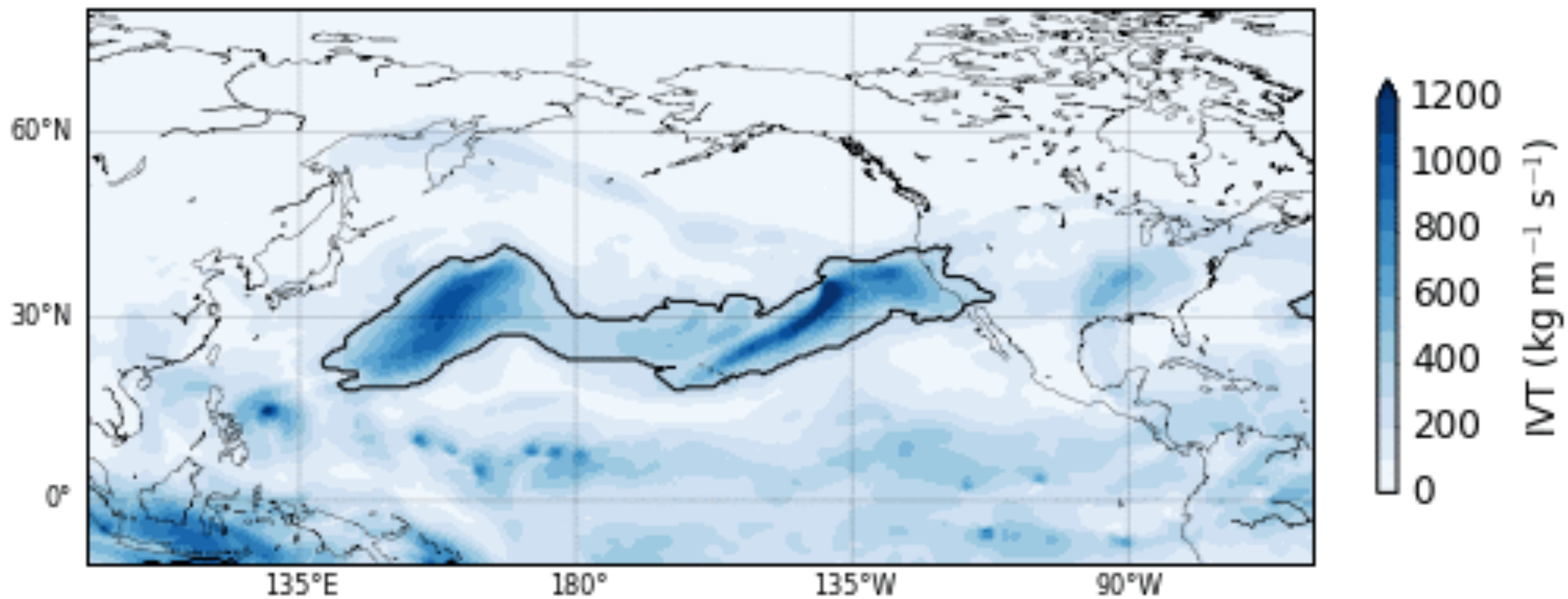


Lora et al. (2016)



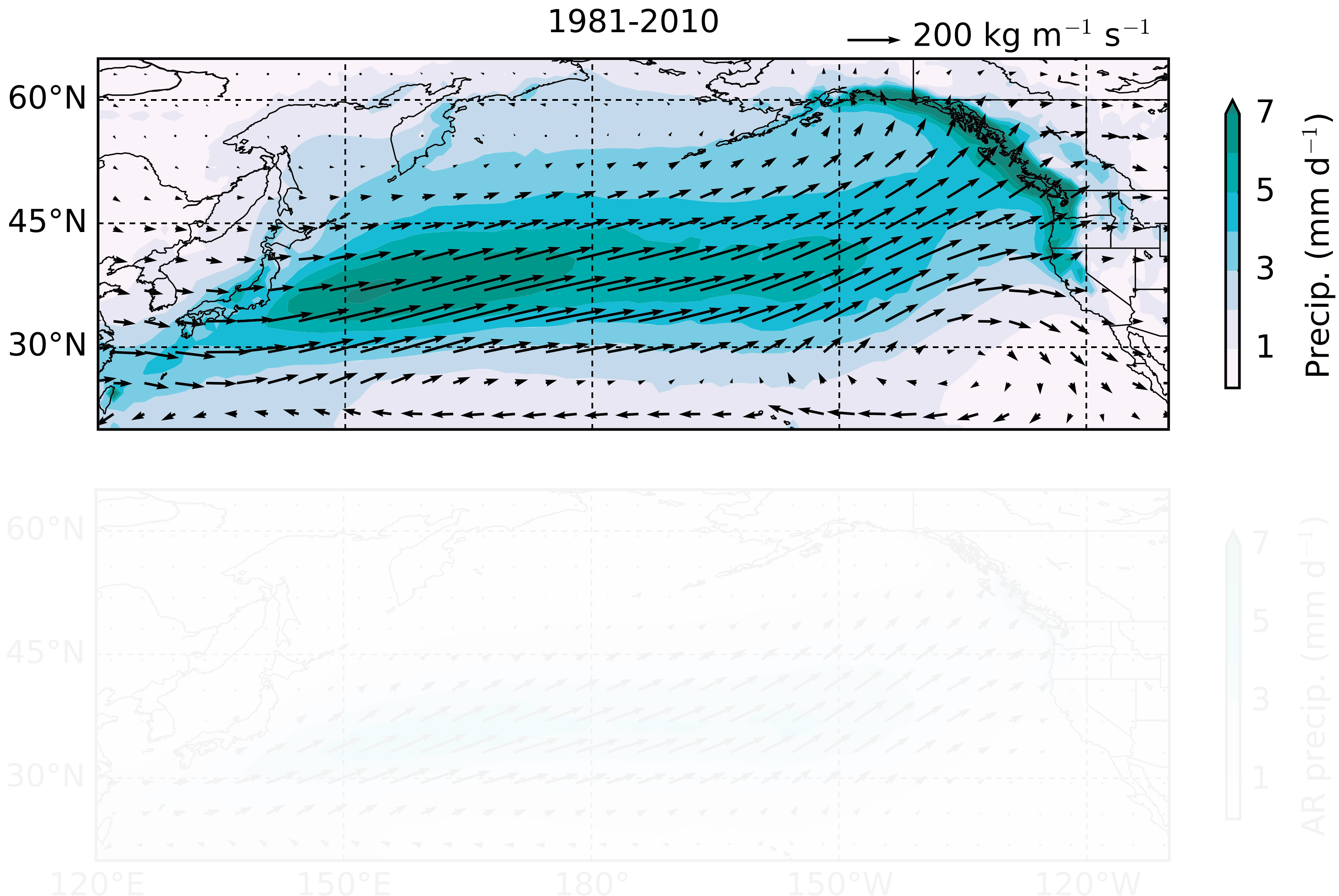
Lora et al. (2016)

North Pacific Atmospheric Rivers Identified in Integrated Vapor Transport (IVT)



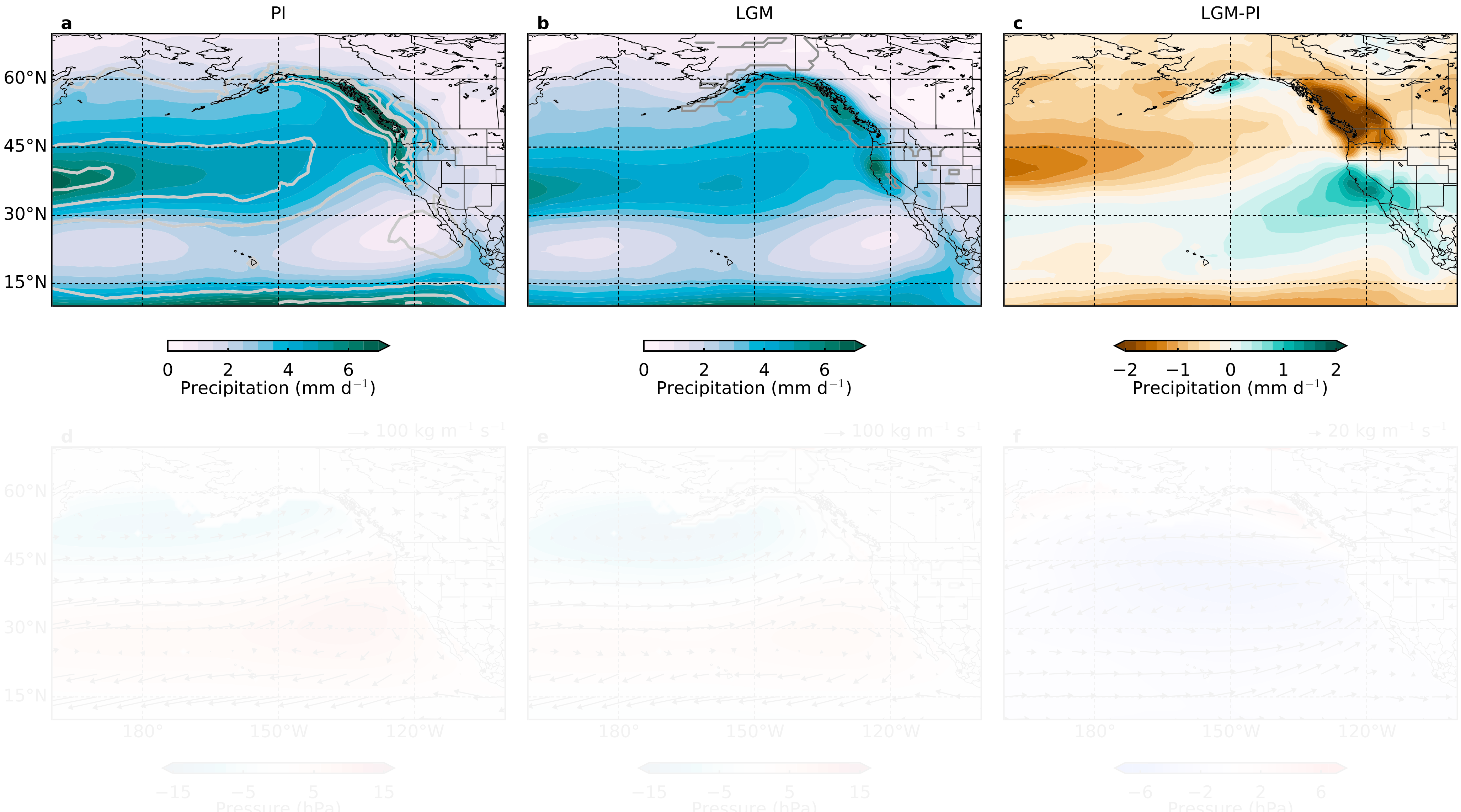
Atmospheric river tracking algorithm (Lora et al., 2017)
February, 2017 MERRA-2 Reanalysis

Moisture Transport by Atmospheric Rivers is Significant



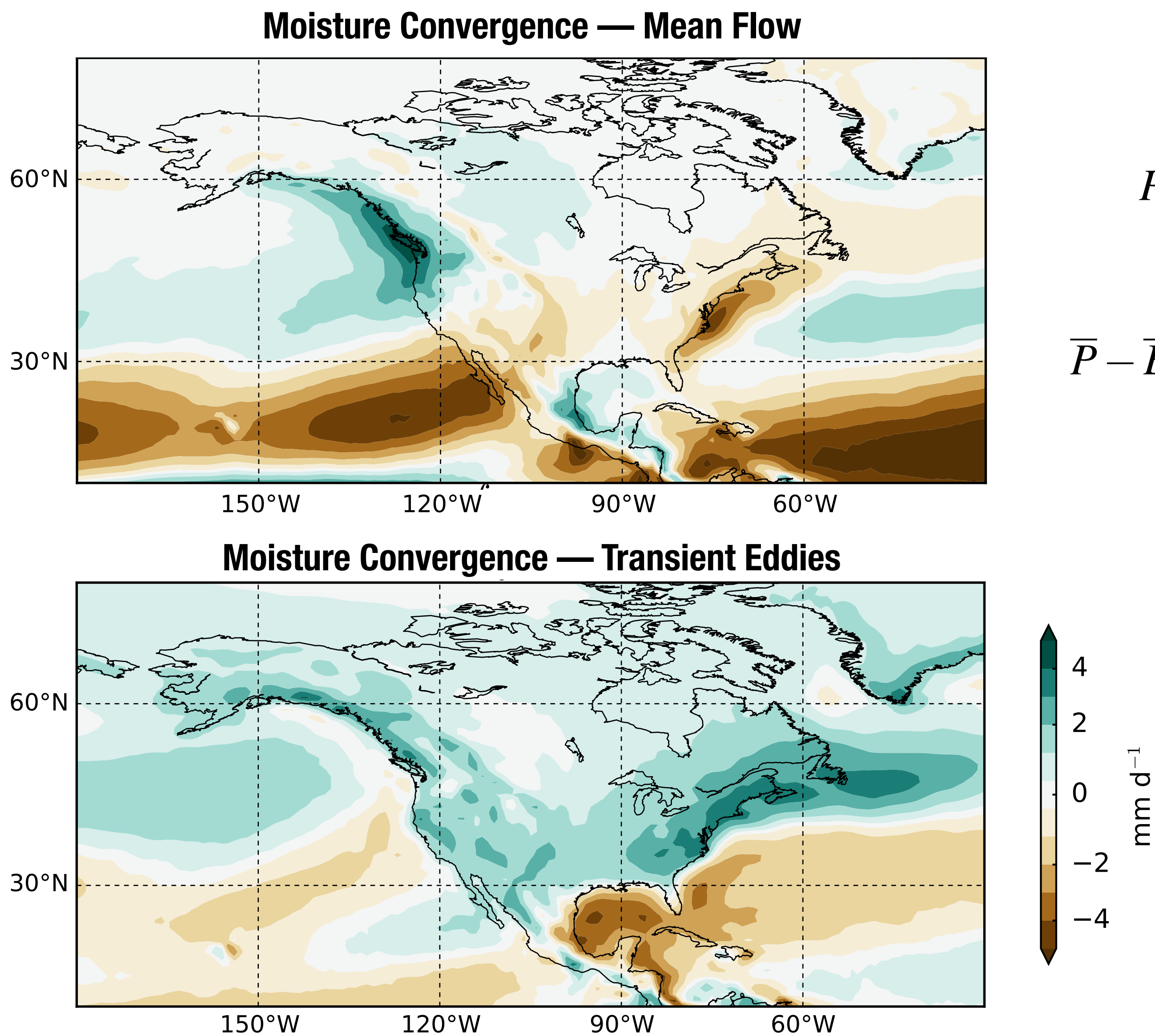
30 years of MERRA-2 Reanalysis (winter half-year mean)

Precipitation Changes Are Organized by Changes of the Low-Level Circulation and Resulting Moisture Transport



Lora et al. (2017)

P–E Results from Atmospheric Moisture Convergence by the Mean Flow and Transient Systems

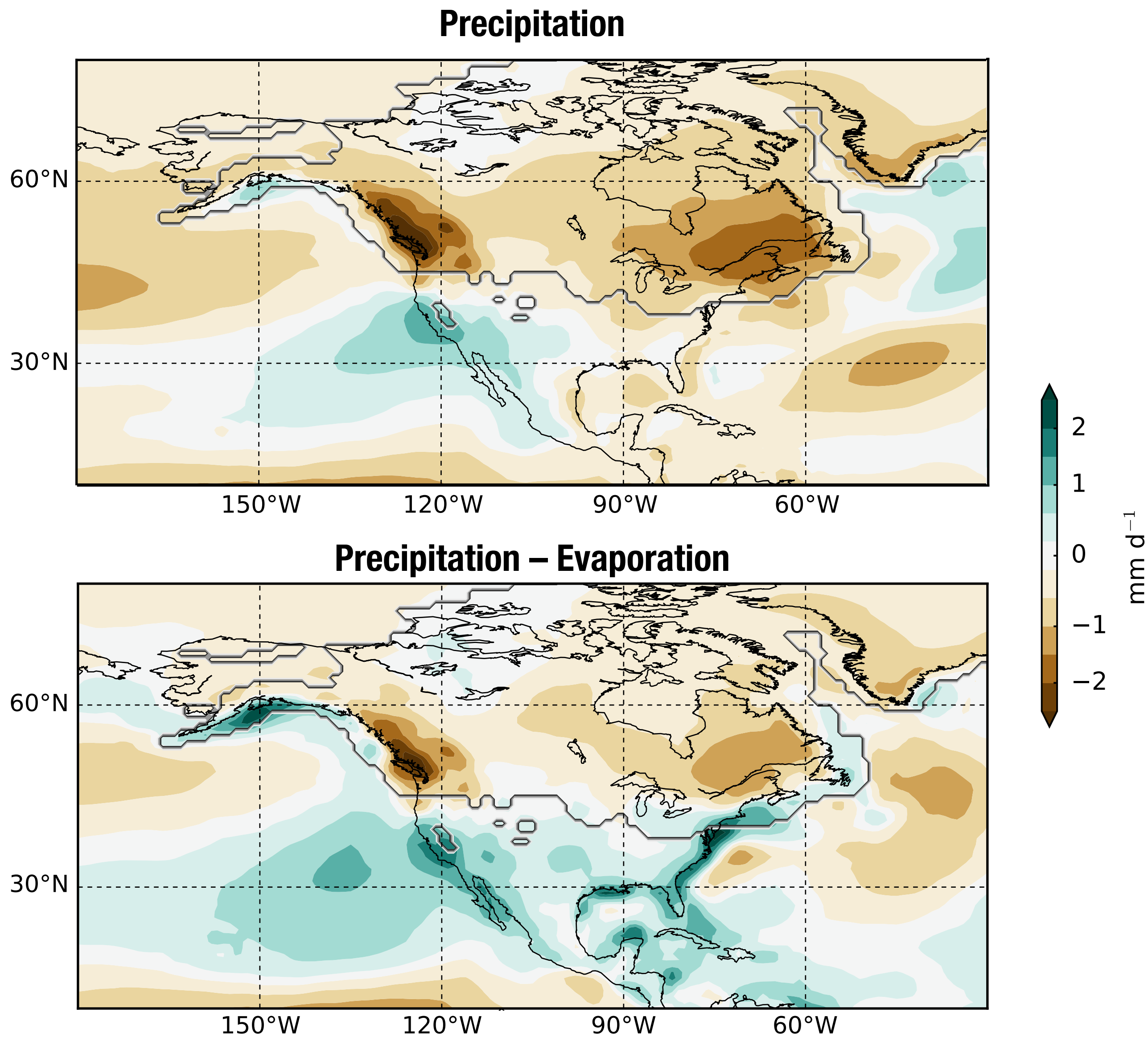


$$P - E = -\frac{1}{\rho g}\nabla \cdot \int_0^{p_s} \mathbf{u} q \, dp$$

$$\overline{P} - \overline{E} \approx -\frac{1}{\rho g}\nabla \cdot \int_0^{p_s} (\bar{\mathbf{u}}\bar{q} + \overline{\mathbf{u}'q'})\overline{dp}$$

Lora (2018), J. Climate

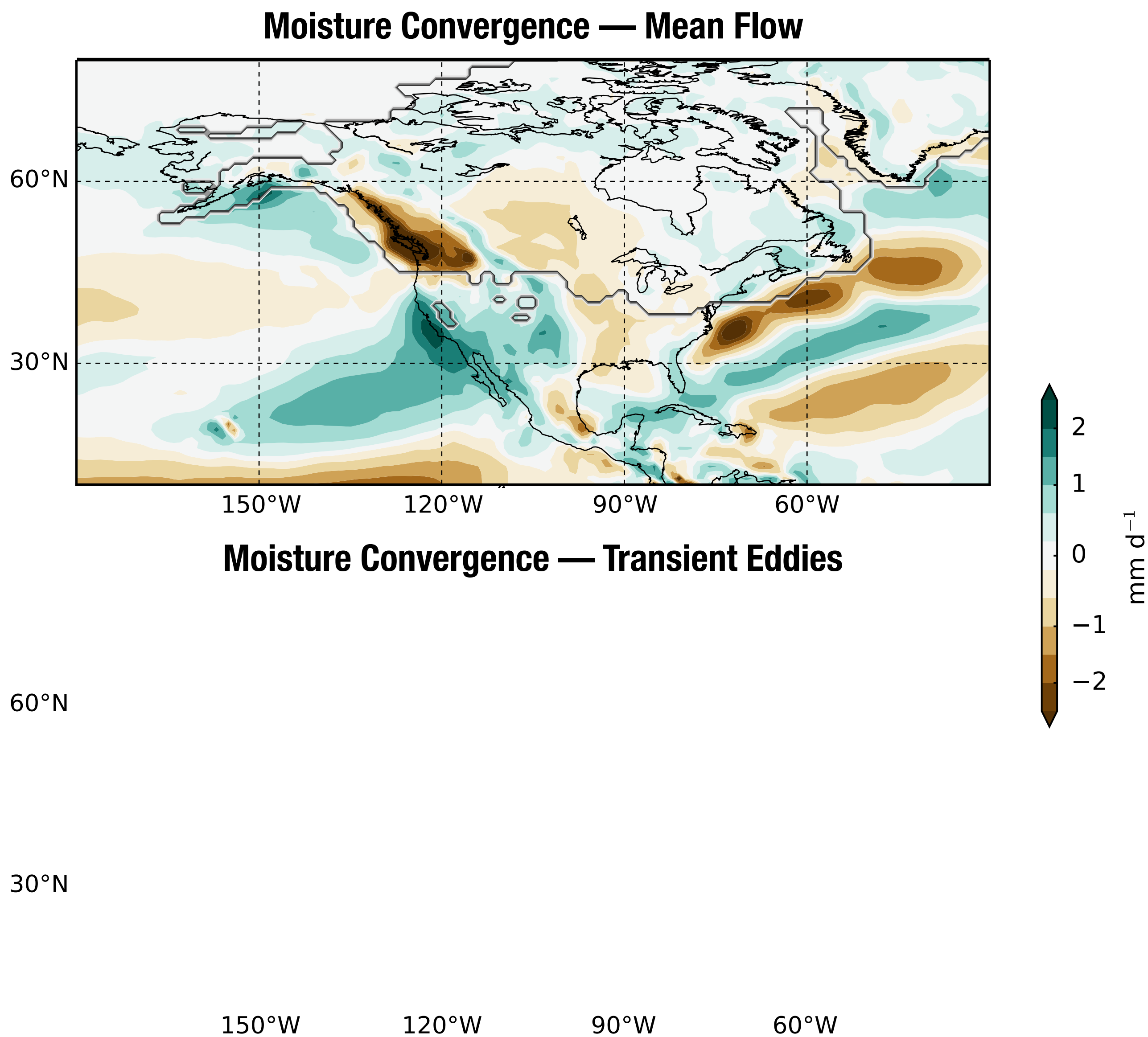
Simulation Differences Show More Precipitation and Less Evaporation at the Last Glacial Maximum…



Winter half-year differences between LGM and Pre-Industrial (9 model ensemble mean)

Lora (2018), J. Climate

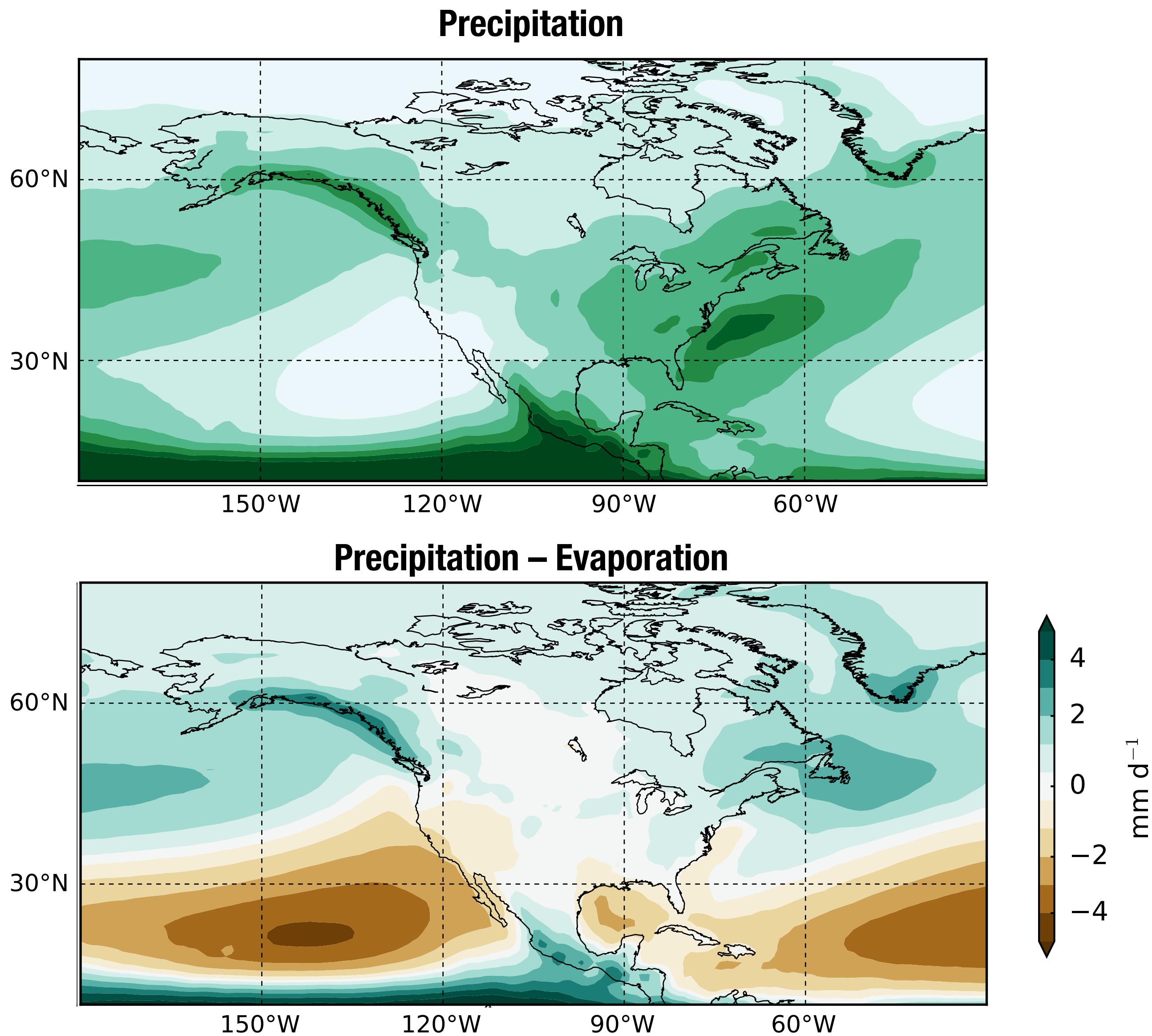
…With Moisture Convergence Changes Dominated by the Mean Flow, Not Transient Eddies!



Winter half-year differences between LGM and Pre-Industrial (9 model ensemble mean)

Lora (2018), J. Climate

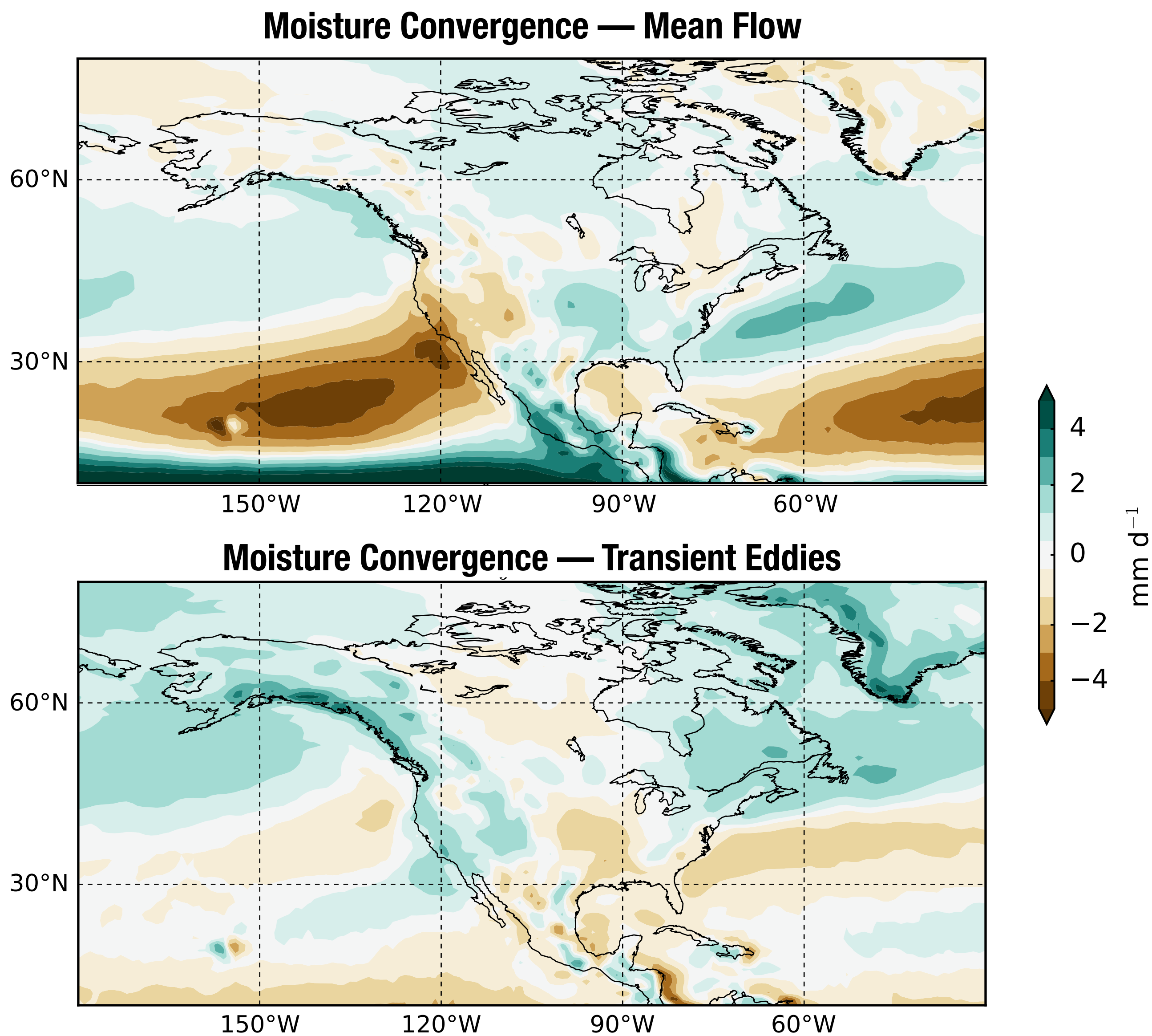
Modern (Pre-Industrial) Moisture Budget: Summer



Summer half-year P and E

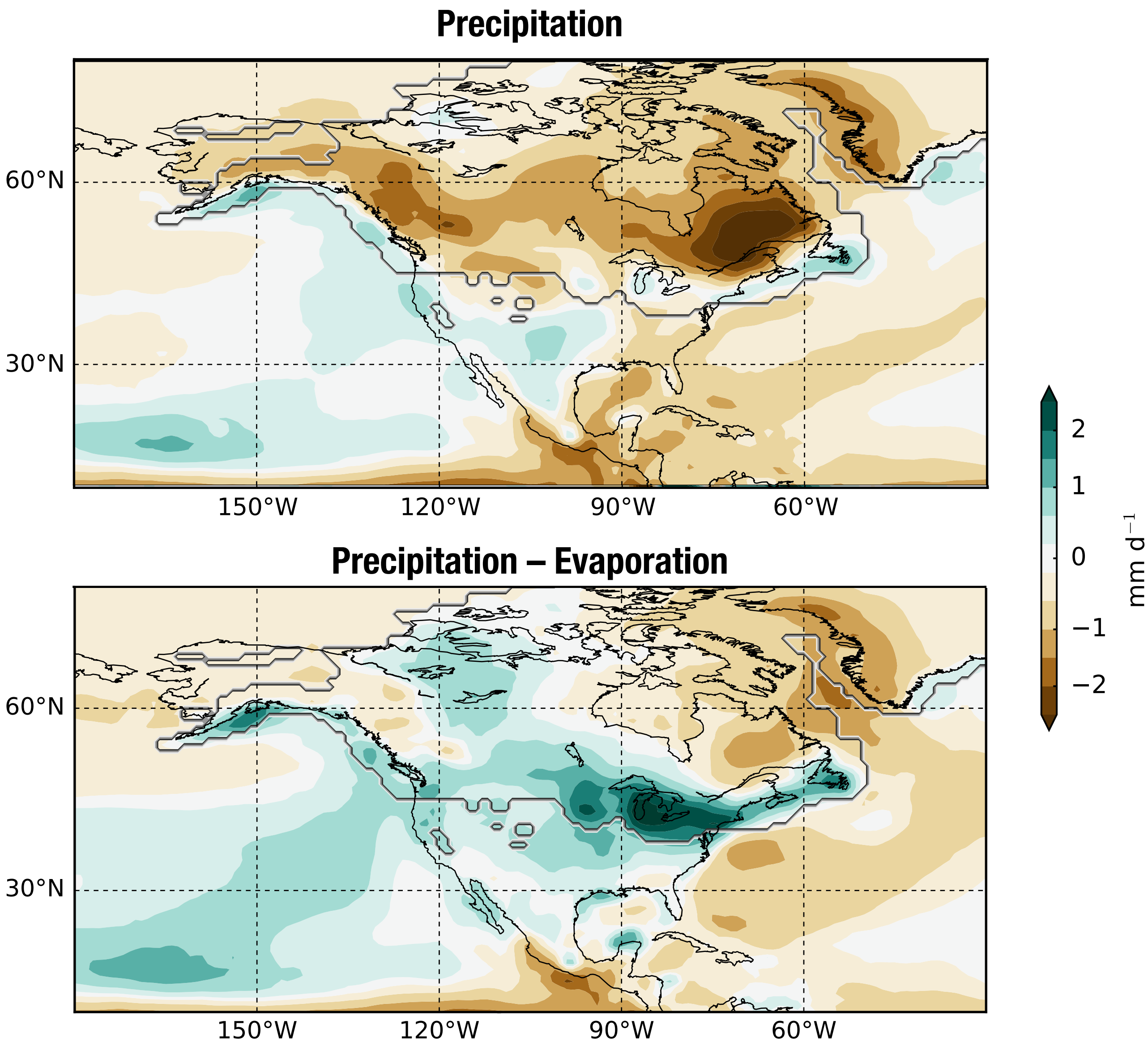
Lora (2018), J. Climate

Modern (Pre-Industrial) Moisture Budget: Summer



Lora (2018), J. Climate

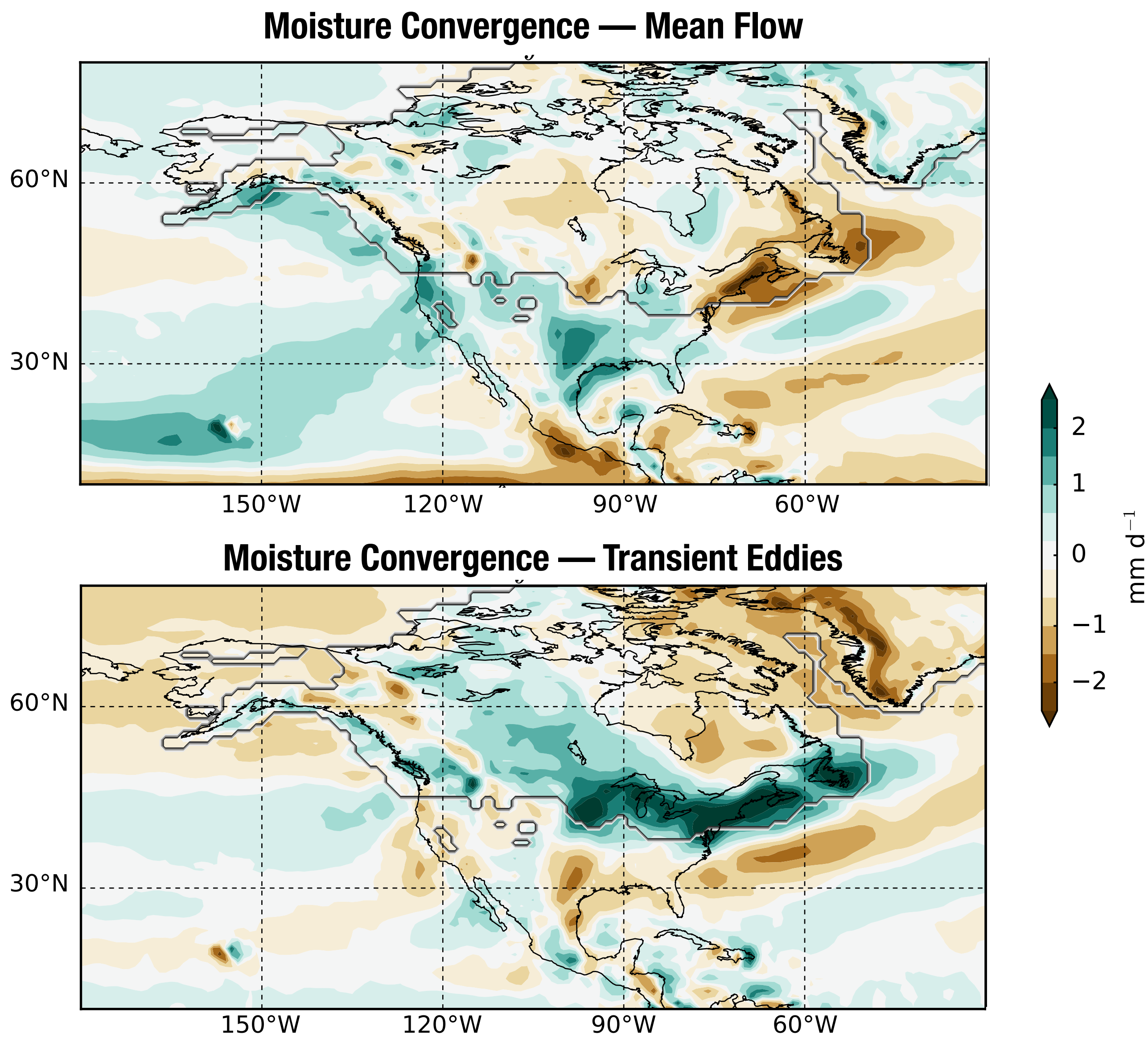
LGM–PI Moisture Budget: Summer



Summer half-year differences between LGM and PI (9 model ensemble mean)

Lora (2018), J. Climate

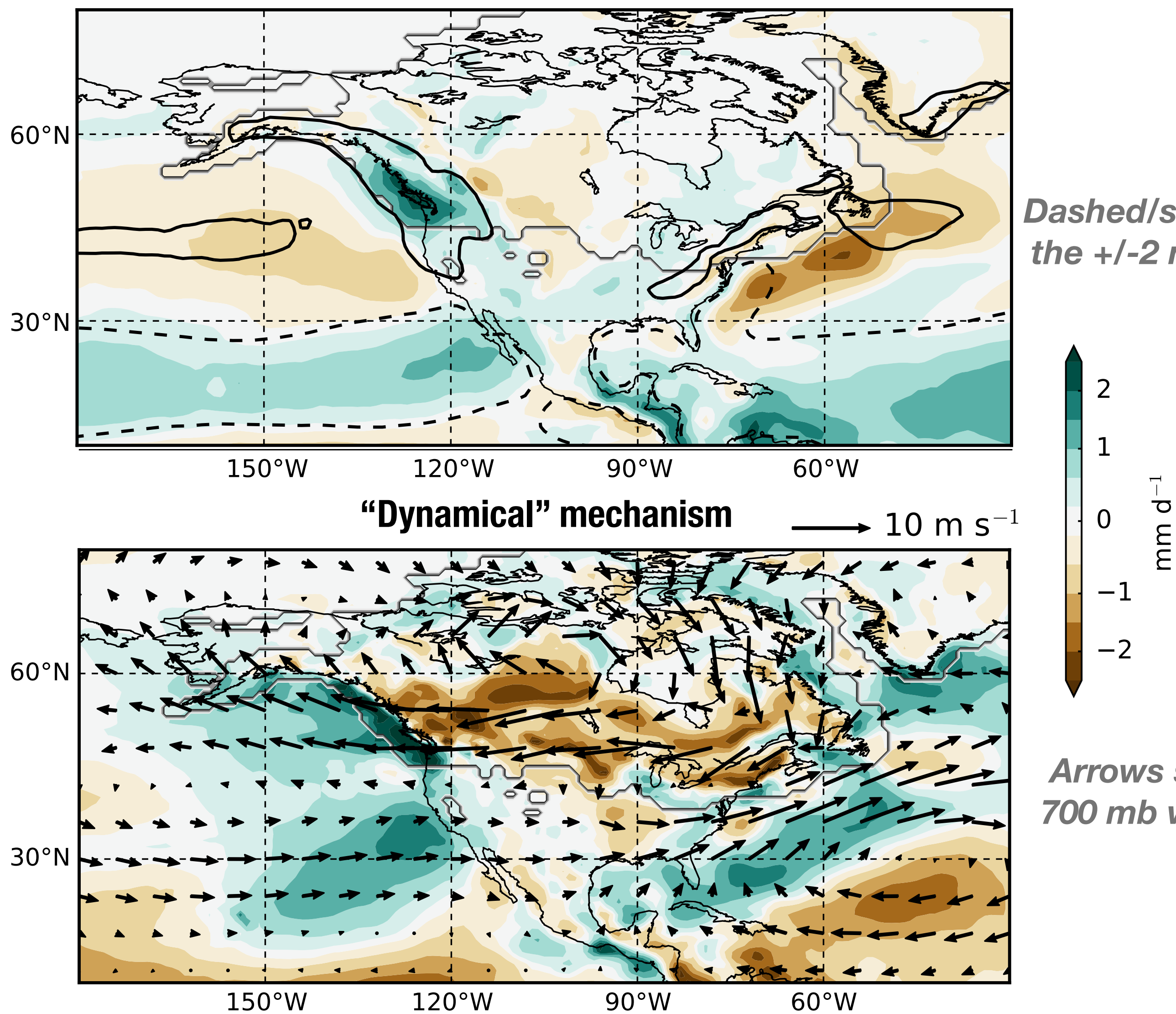
LGM–PI Moisture Budget: Summer



Summer half-year differences between LGM and PI (9 model ensemble mean)

Lora (2018), J. Climate

LGM–PI hydroclimate changes: Mechanisms



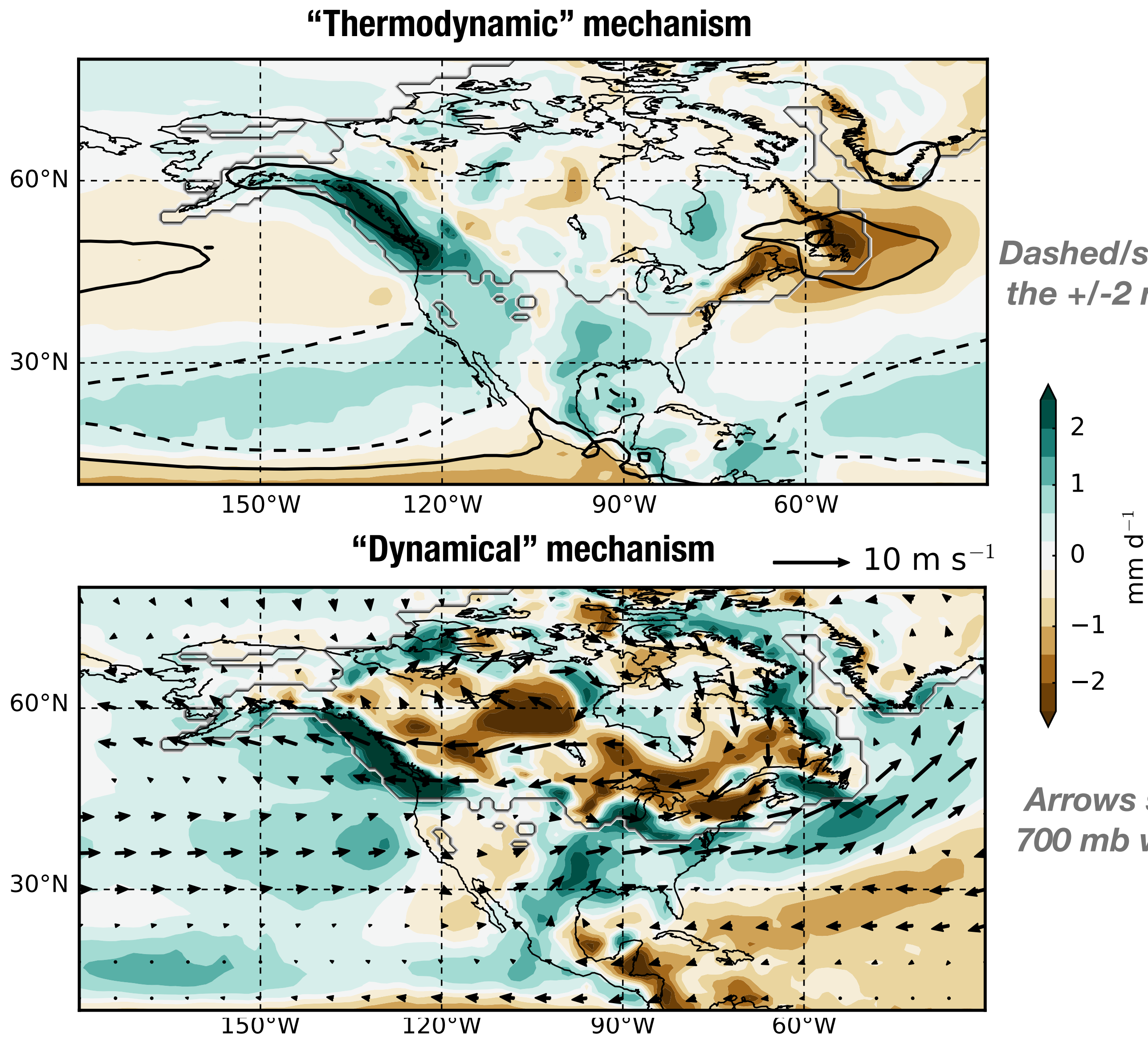
Dashed/solid contours show the +/-2 mm d^{-1} P–E from PI

Winter half-year differences between LGM and PI (9 model ensemble mean)

Arrows show the LGM–PI 700 mb wind anomaly field

Lora (2018), J. Climate

LGM–PI hydroclimate changes: Mechanisms



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