Understanding and predicting the U.S. hydroclimate from weather regimes and climate perspectives

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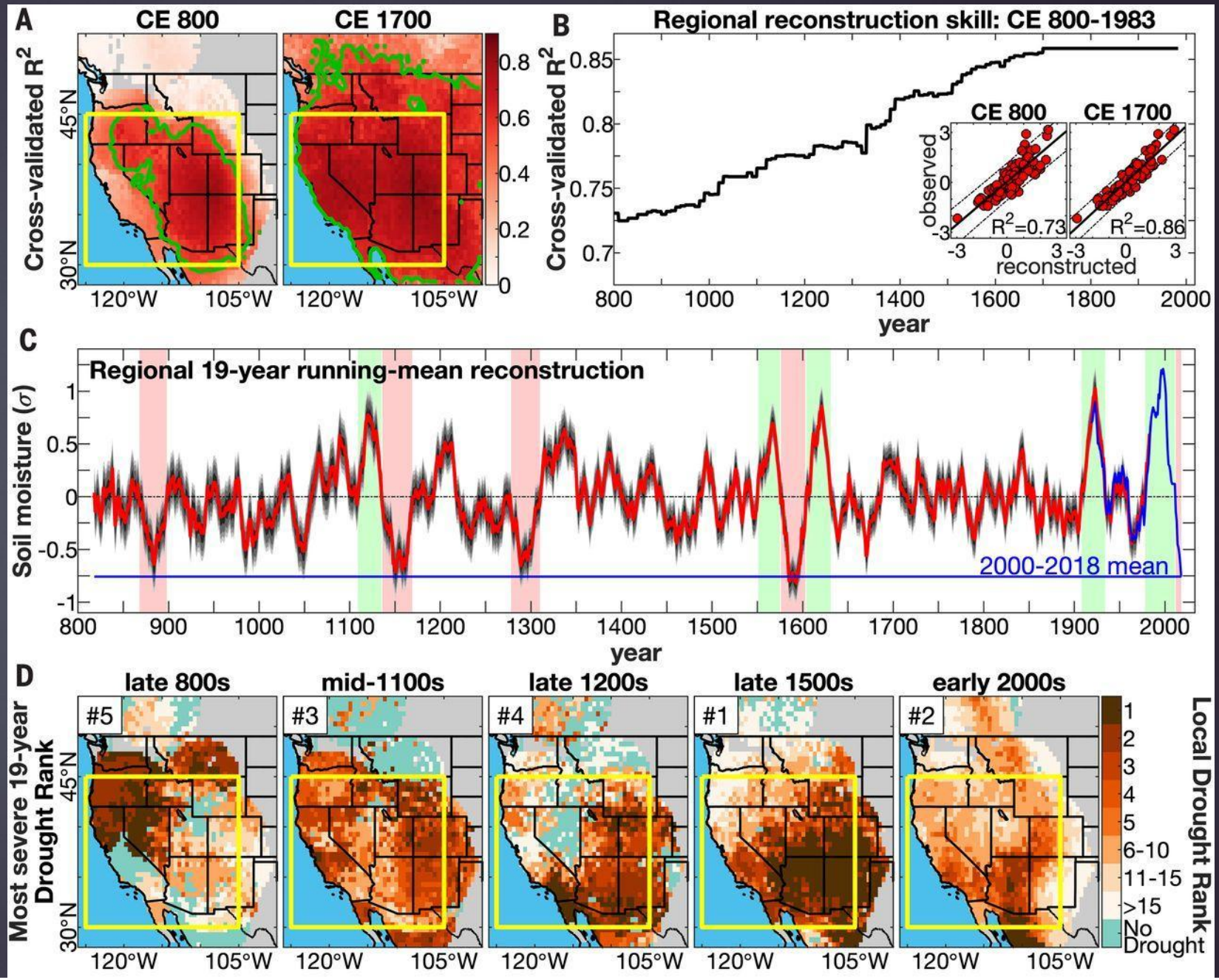
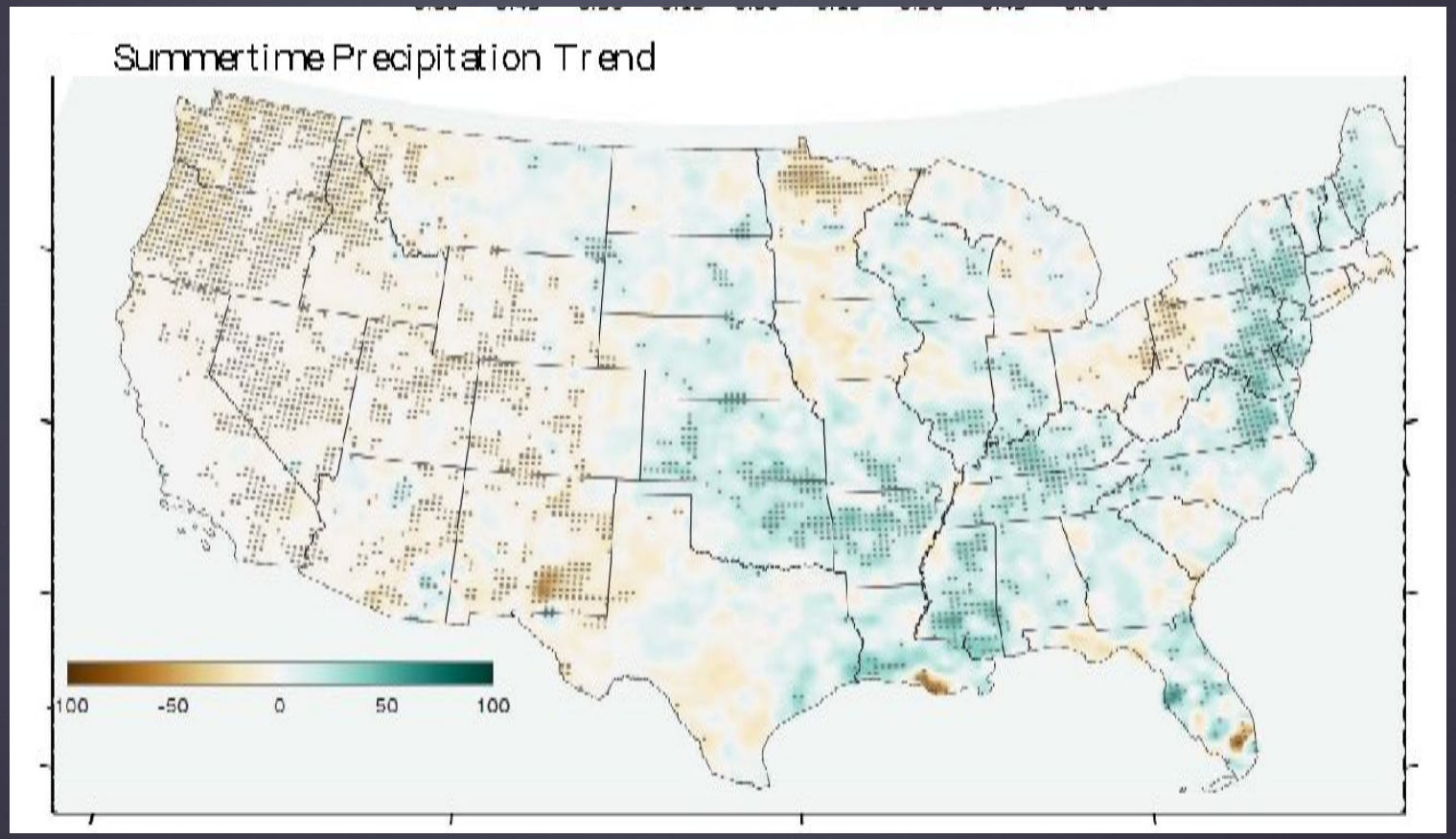
From a paleoclimate perceptive, the Western U.S. entered a megadrought particularly in the Southwestern in the early 2000s



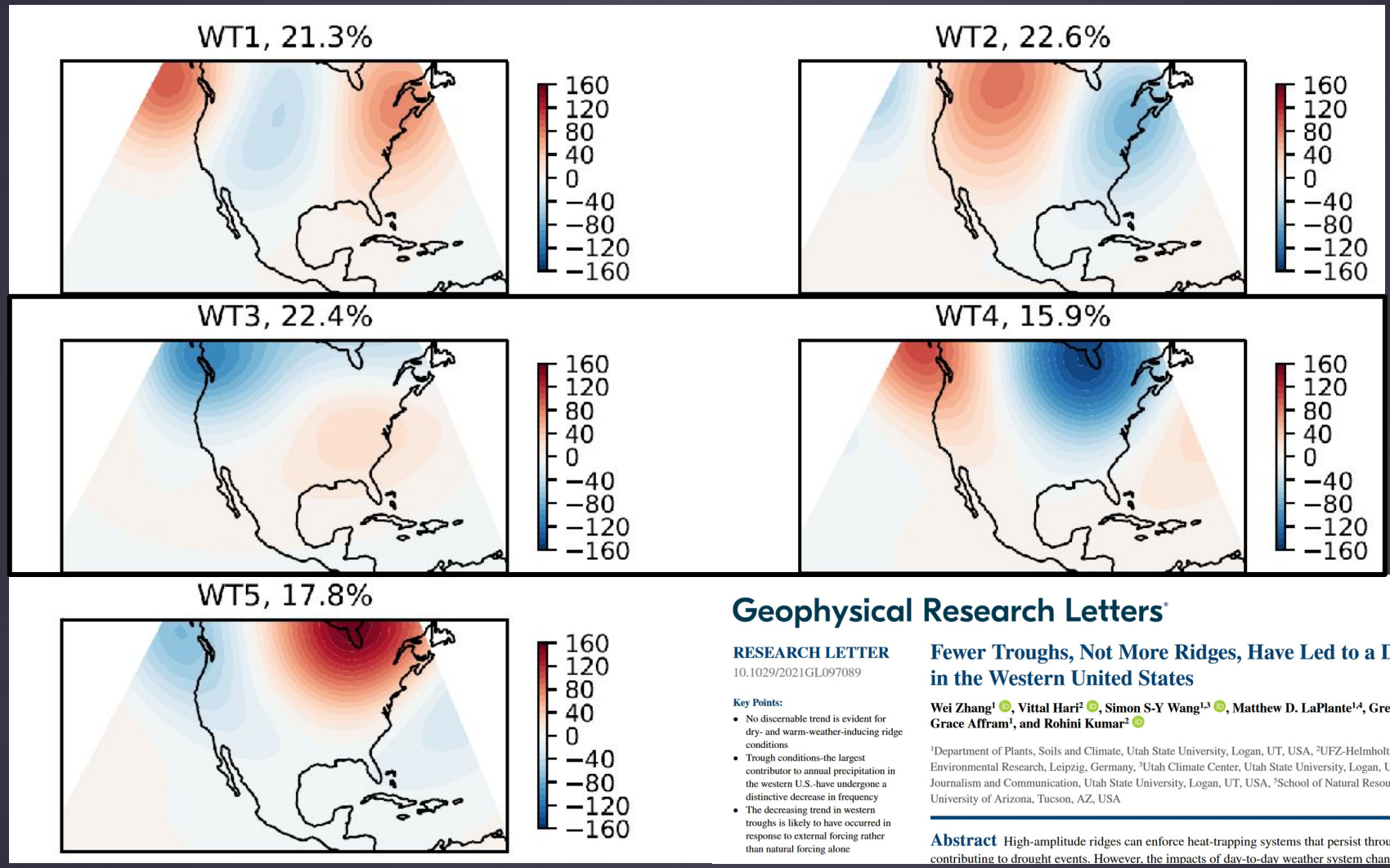
Williams et al. 2020, Science

Significant decreasing/increasing trends in summertime precipitation are found across the Western/Eastern U.S.

Two Americas: one parched, one soaked



Five clusters or *weather types (WT)/regimes* are identified from daily 500-hPa geopotential height anomalies by k-means cluster analysis



Geophysical Research Letters

RESEARCH LETTER
10.1029/2021GL097089

Fewer Troughs, Not More Ridges, Have Led to a Drying Trend in the Western United States

Key Points:

- No discernable trend is evident for dry- and warm-weather-inducing ridge conditions
- Trough conditions-the largest contributor to annual precipitation in the western U.S.-have undergone a distinctive decrease in frequency
- The decreasing trend in western troughs is likely to have occurred in response to external forcing rather than natural forcing alone

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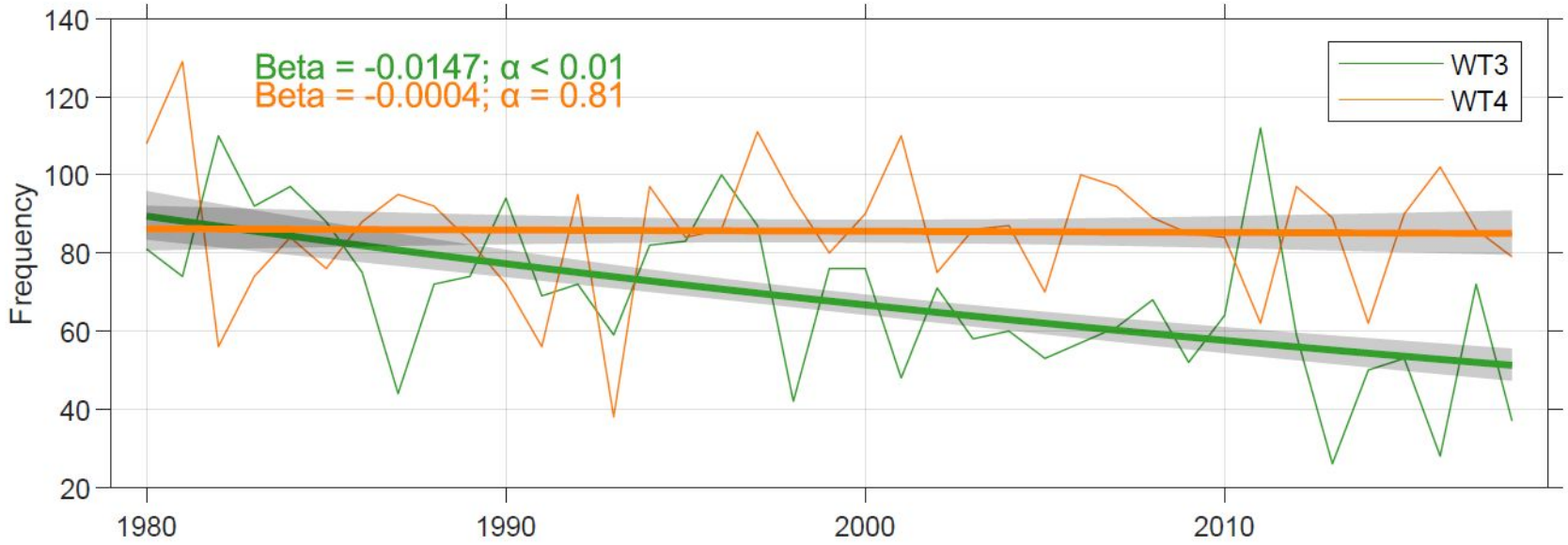
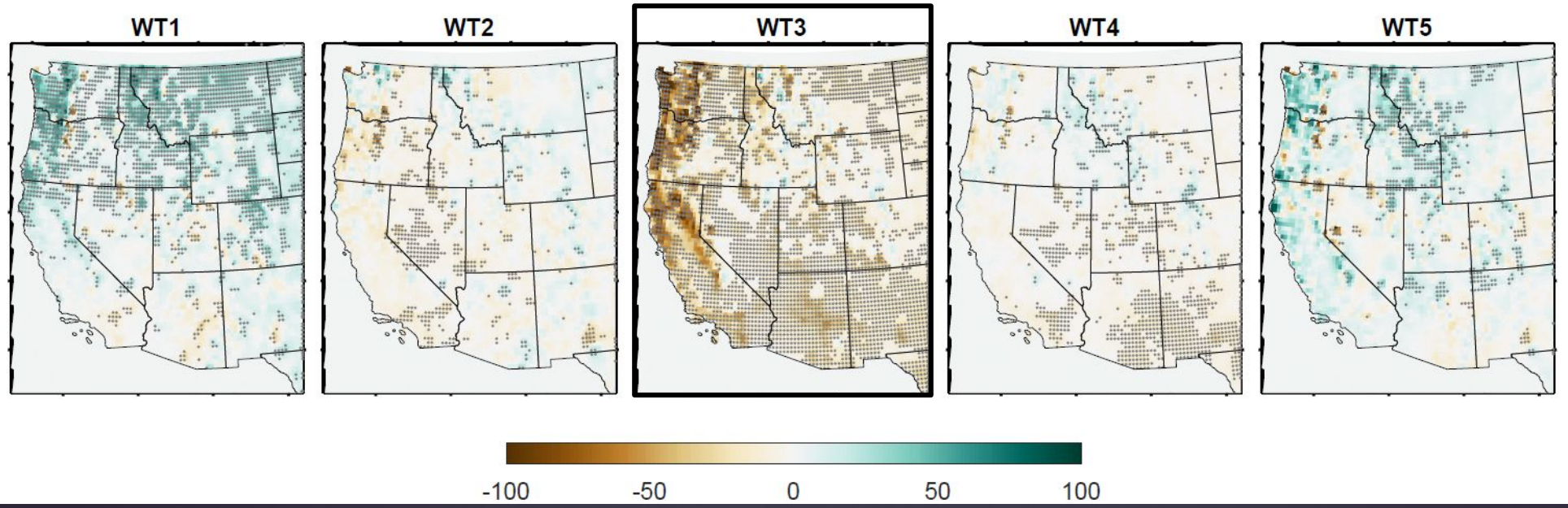
Abstract High-amplitude ridges can enforce heat-trapping systems that persist through an entire season, contributing to drought events. However, the impacts of day-to-day weather system changes at the meso- and

Zhang et al. 2019; 2021; Zhang and Villarini 2021

Weather regime is a potential predictor for droughts

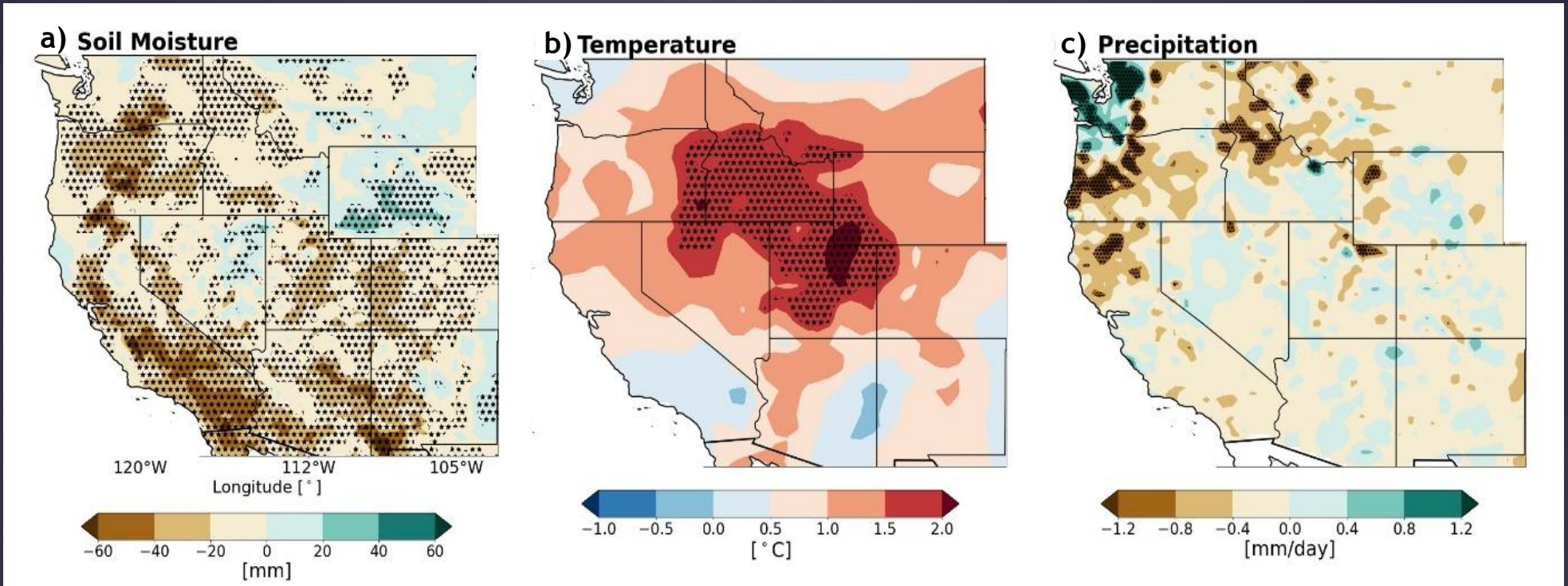




Dry patterns (WT4) are not increasing, but wet patterns (WT3) are decreasing, responsible for the drying trend in the Western U.S.

Zhang et al.,2021

Characterizing the Drivers of the Western U.S. Droughts



Affram et al., 2023

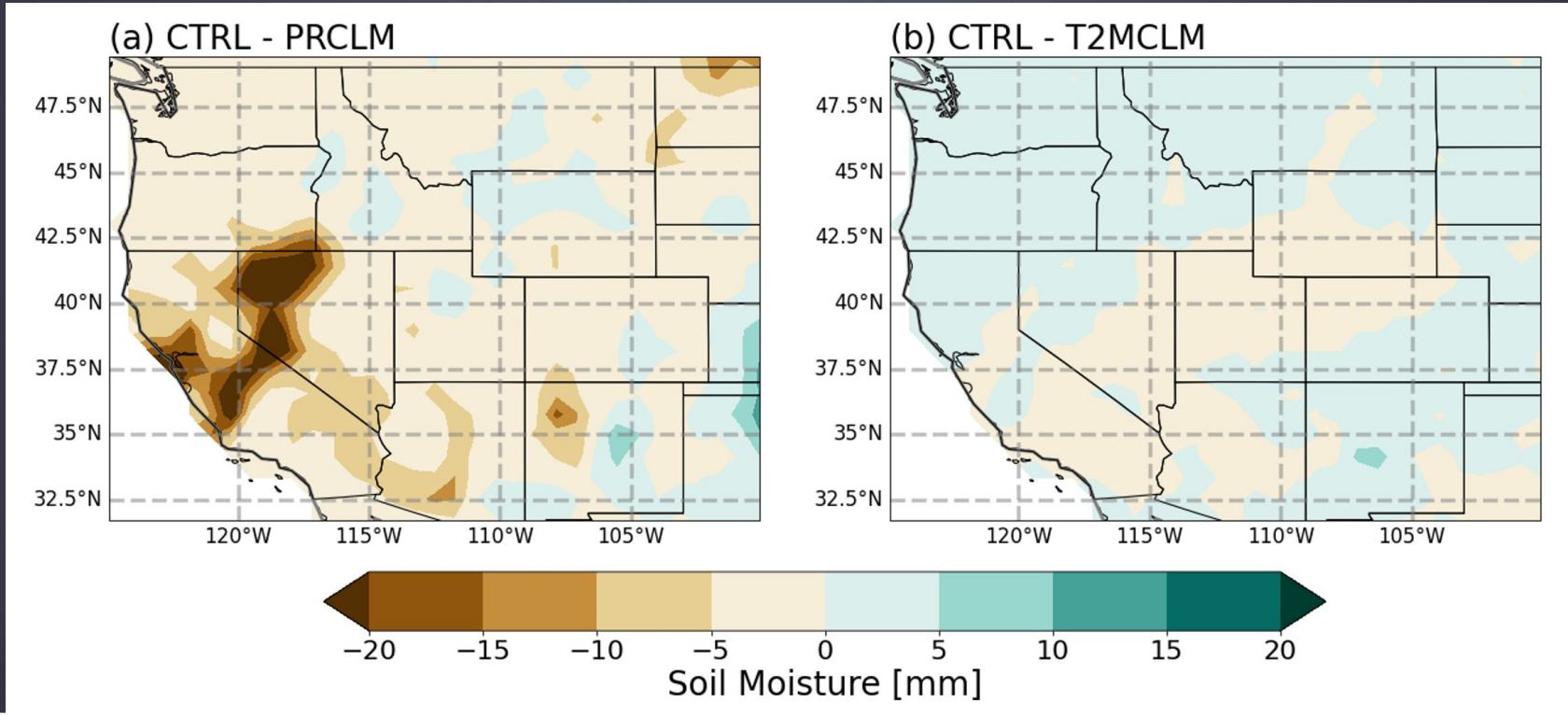
Water Balance Equation:

Change in soil moisture (ΔS) = Precipitation (P) - Evapotranspiration (ET)$_{Temperature}$ - Runoff (R)

High temperatures exert **weaker** impacts on soil moisture deficit

Method:

- CTRL – Met forcings across the Western U.S. in 2021
- PRCLM – Substituted precipitation in CTRL with its climatology (1981-2010)
- T2MCLM – Same as above but with temperature climatology



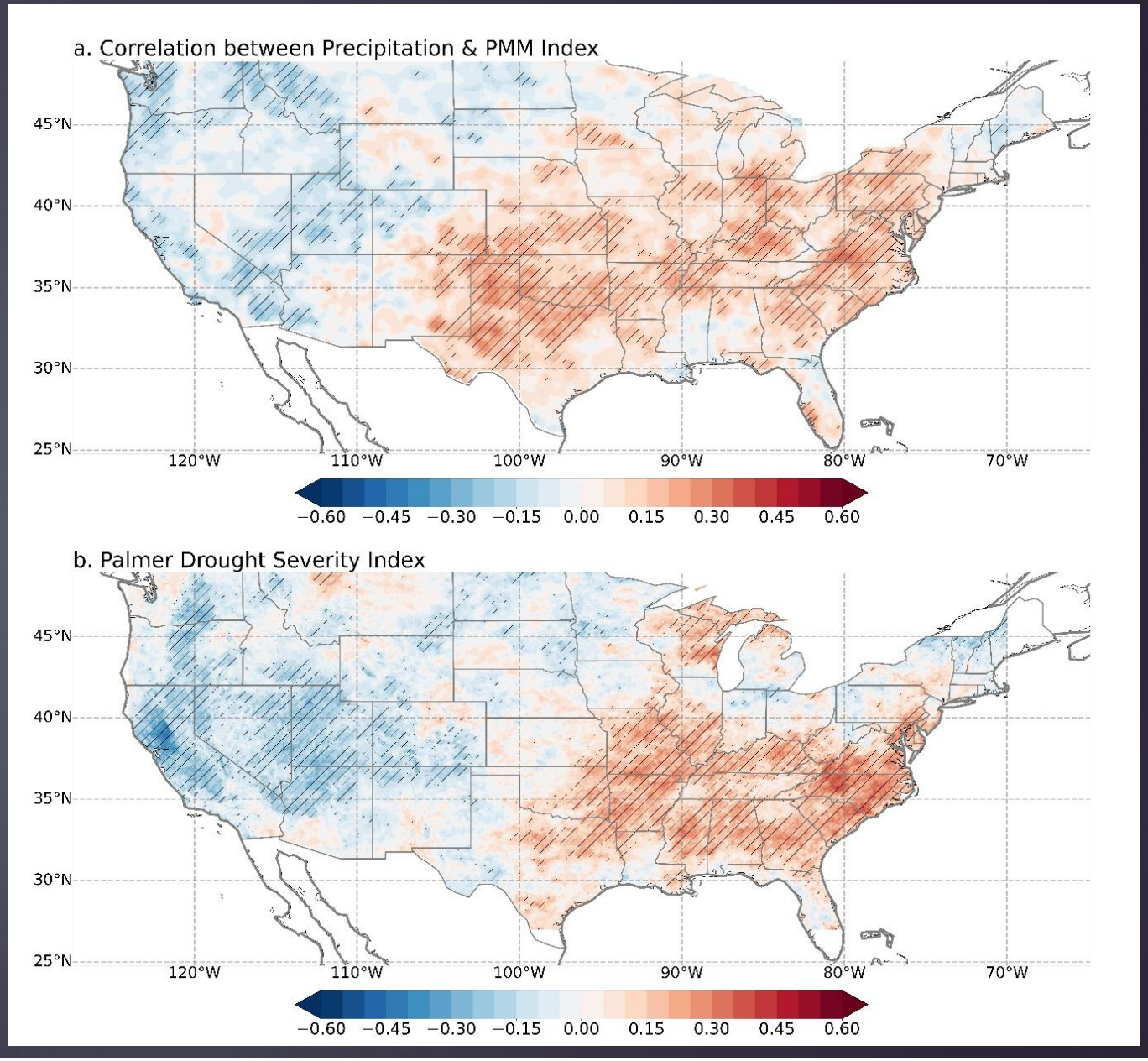
Affram et al., 2023

Soil Moisture responses from model experiments

The Pacific Meridional Mode (PMM) Precipitation Relationship

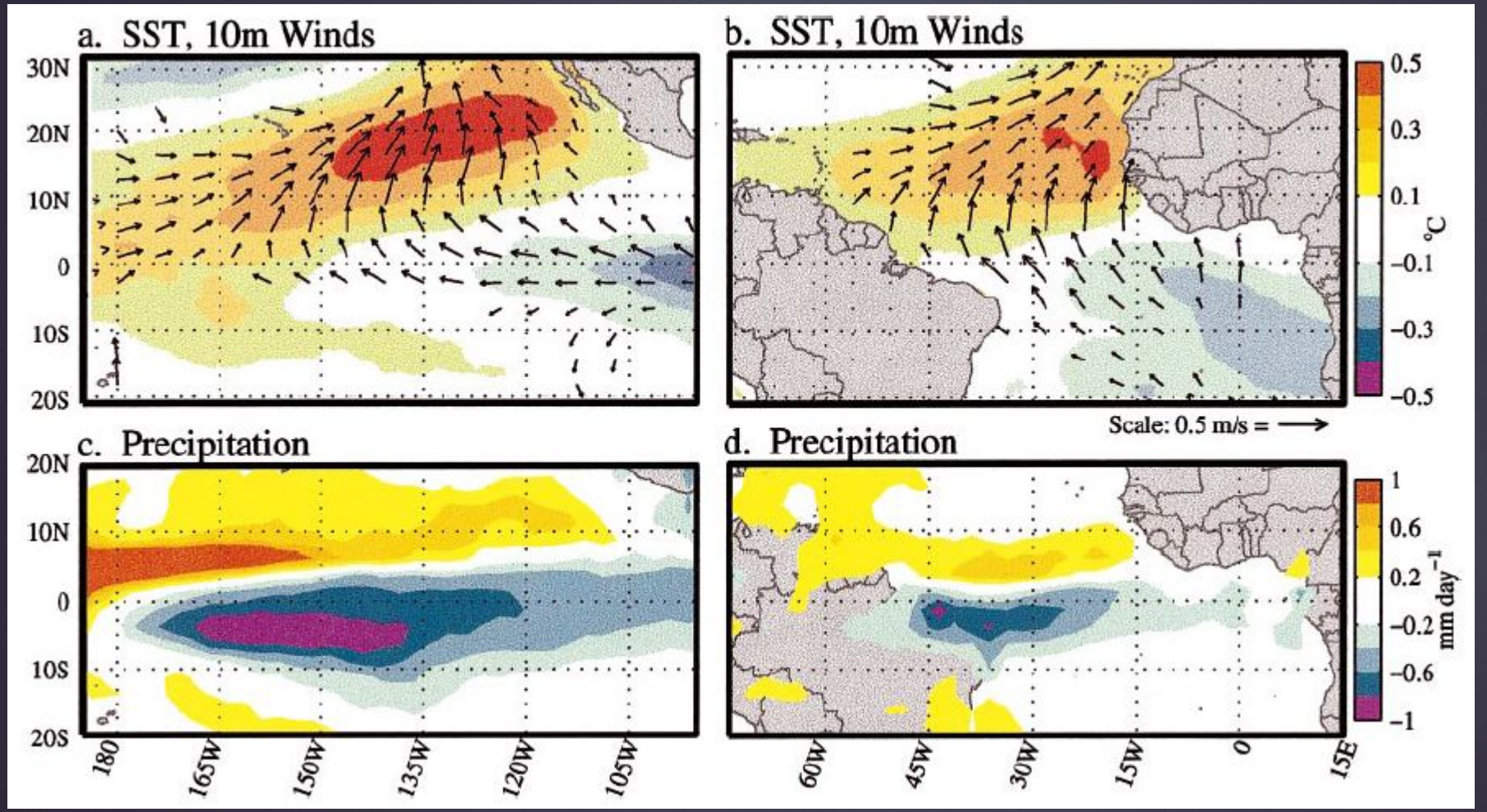
PMM exhibits a significant association with the dry-West & wet-East summertime precipitation pattern

Hypothesis: PMM could affect precipitation variability in the CONUS by teleconnections



PMM is the leading mode of a fully coupled ocean and atmosphere variability in the subtropical Eastern Pacific.

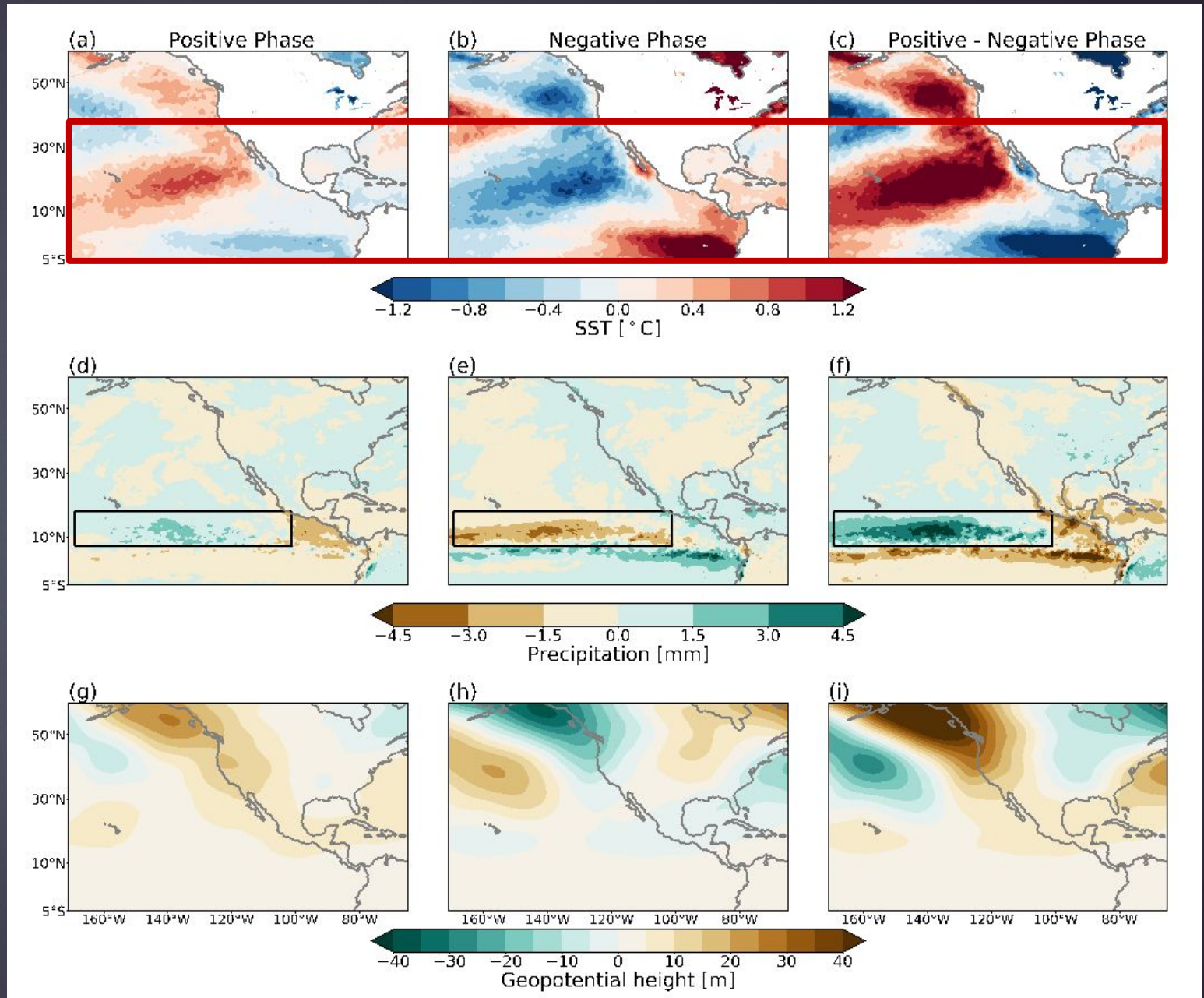
The PMM Index is defined by applying Maximum Covariance Analysis (MCA) to tropical Pacific SST & 10m winds.



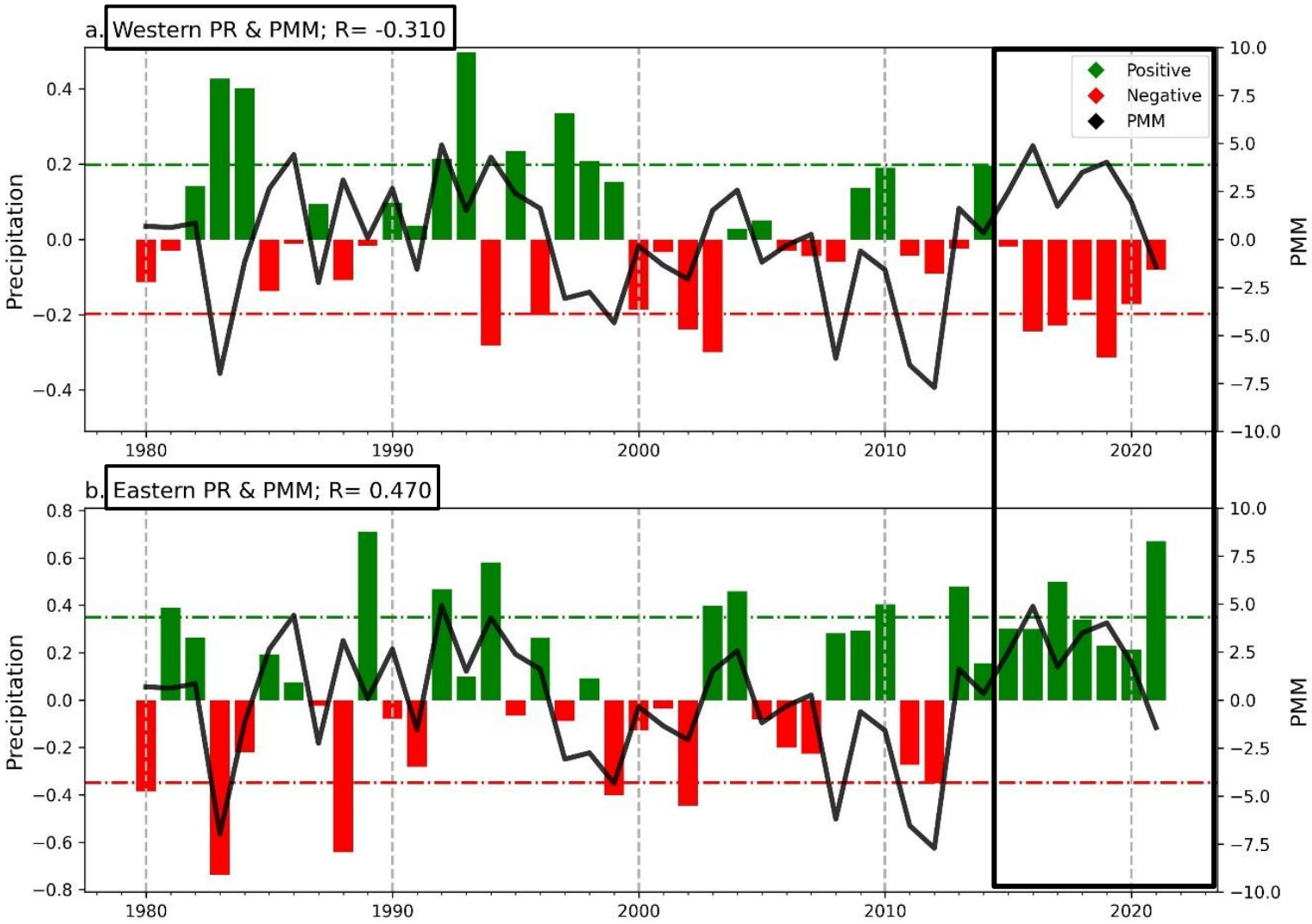
PMM-related SST anomalies can weaken trade winds & reduce evaporation, thereby expanding warm water towards the equator & potentially causing ENSO

Chiang and Vimont (2004)

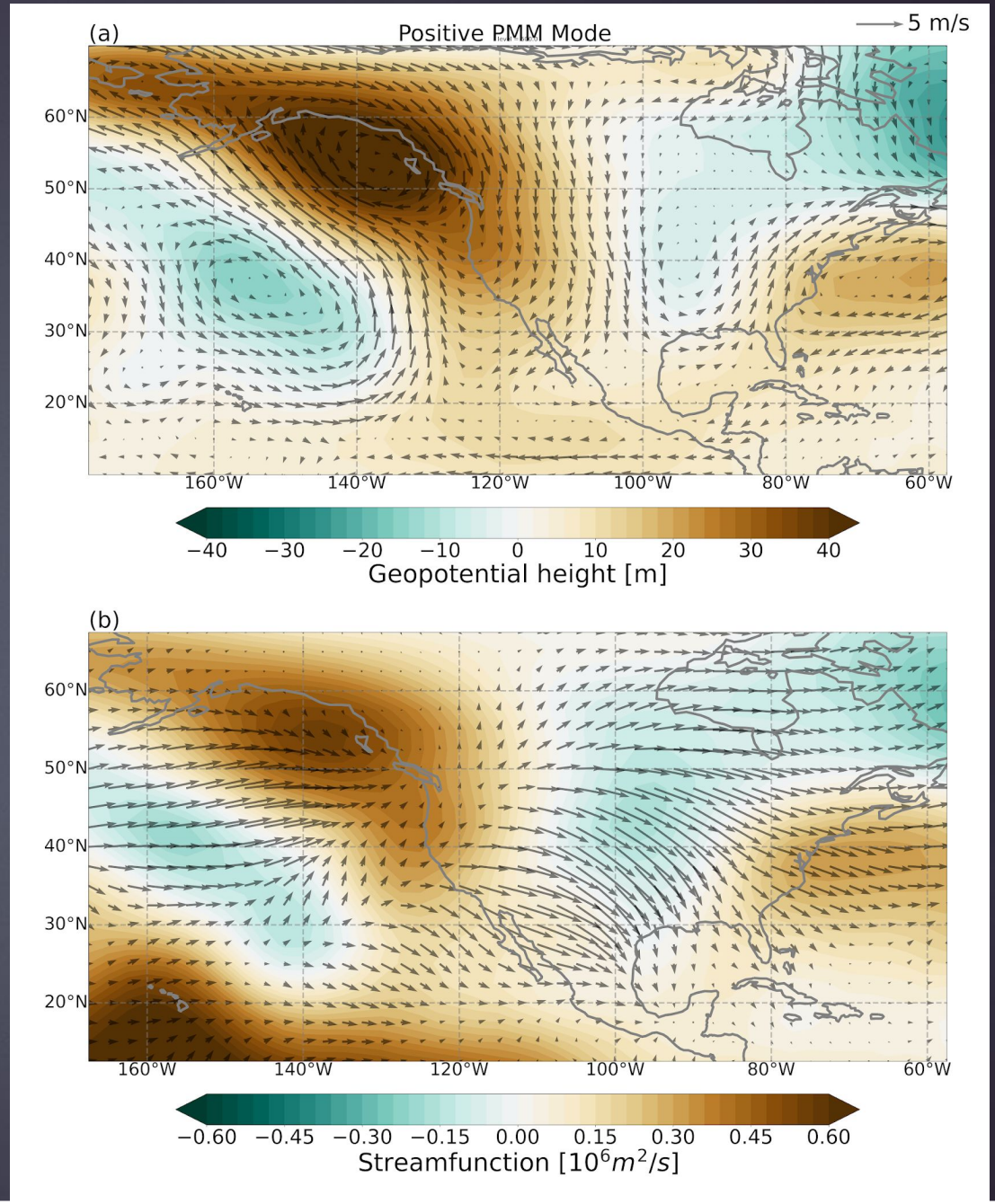
Method: Years with annual anomalies **greater/less** than 1STD of the PMM index were deemed **positive/negative** phases of the PMM with the removal of strong **ENSO** years.



Positive PMM reduces precipitation in the West (r=-0.31) & increases precipitation in the East (r=0.47).

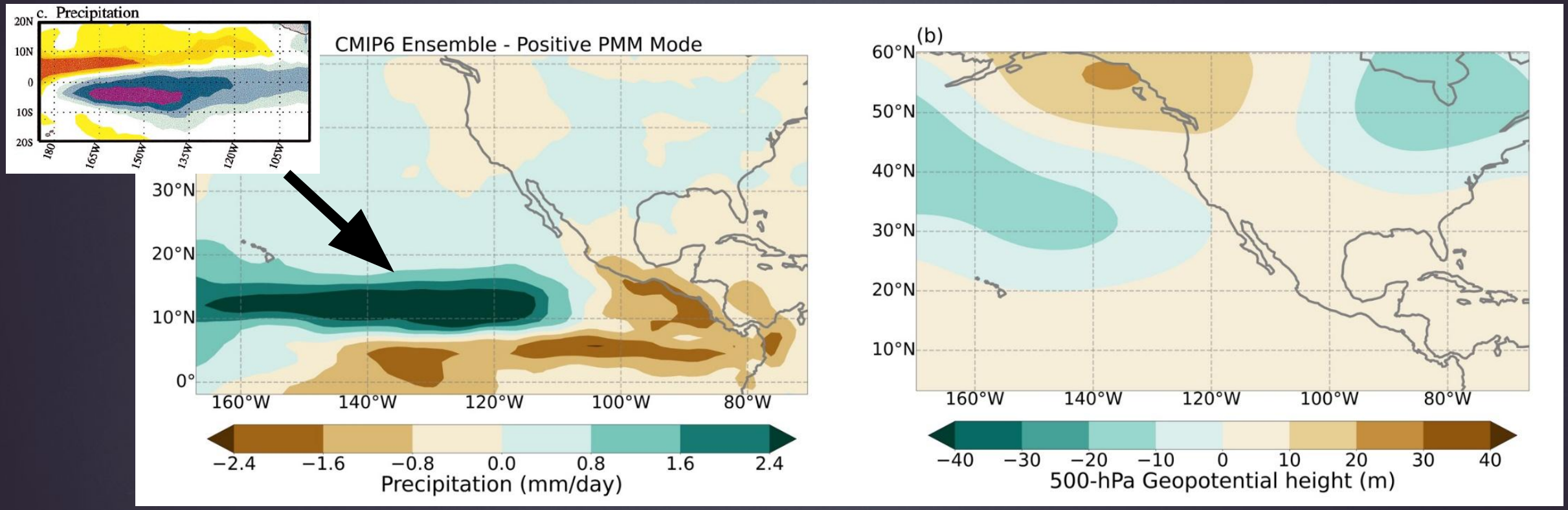


PMM-related large scale circulation patterns are consistent with precipitation changes, with wave trains propagating from the subtropical Pacific to the U.S.



Large-scale circulations reproduced the wave trains in observations thus consistent with less/more precipitation in Western/Eastern U.S. during the Positive PMM phase

Multi-model average of 28 CMIP6 AMIP models – First realization only



Summary / Conclusions

- The decreasing trend in the Western U.S. precipitation was mainly due to fewer trough patterns.
- The 2021 western U.S. drought was mainly driven by precipitation deficit with increased temperatures acting as a secondary driver.
- The positive PMM phase leads to excessive precipitation across the Eastern U.S., with diminished precipitation over the Western U.S.; the opposite is true for the negative PMM phase.
- CMIP6-AMIP experiments reproduced the associated large-scale circulation patterns in the observations consistent with less/more precipitation in Western/Eastern U.S. during the PMM phases.

Main References

1. Affram, G., Zhang, W., Hipps, L., & Ratterman, C. (2023). Characterizing the development and drivers of 2021 Western US drought. *Environmental Research Letters*, *18*(4), 044040

2. Affram, G., Zhang, W., Ratterman, C., … Gillies R. (2024). Strong Modulation of the Pacific Meridional Mode on the Dipole Pattern of the CONUS Summertime Precipitation (to be submitted)

3. Zhang, W., Hari, V., S-Y Wang, S., LaPlante, M. D., Garfin, G., Affram, G., & Kumar, R. (2022). Fewer troughs, not more ridges, have led to a drying trend in the Western United States. *Geophysical Research Letters*, *49*(1), e2021GL097089

4. Williams, A. P., Cook, E. R., Smerdon, J. E., Cook, B. I., Abatzoglou, J. T., Bolles, K., ... & Livneh, B. (2020). Large contribution from anthropogenic warming to an emerging North American megadrought. *Science*, *368*(6488), 314-318

Thank You!

Questions?

Please send your questions/comments to;

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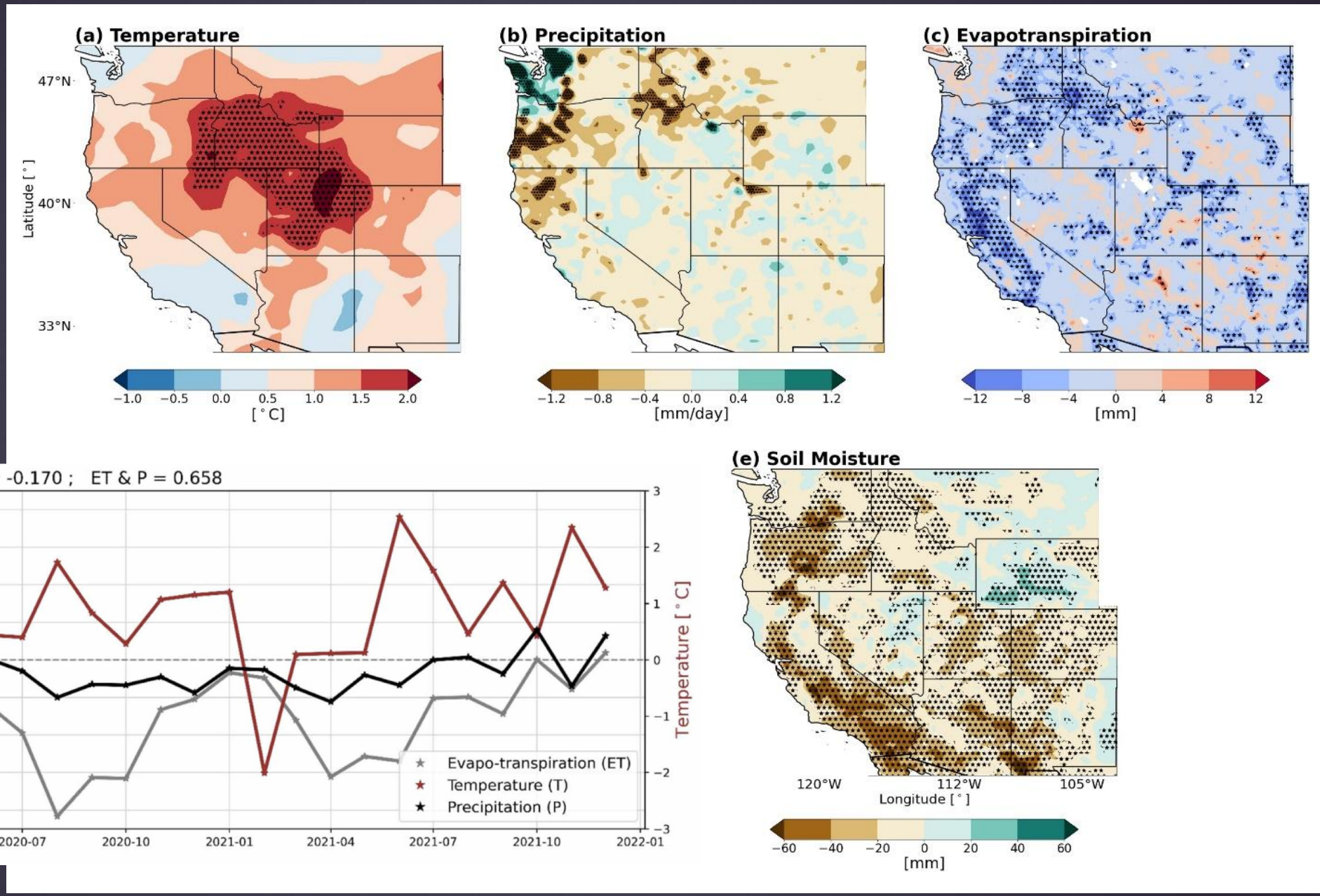
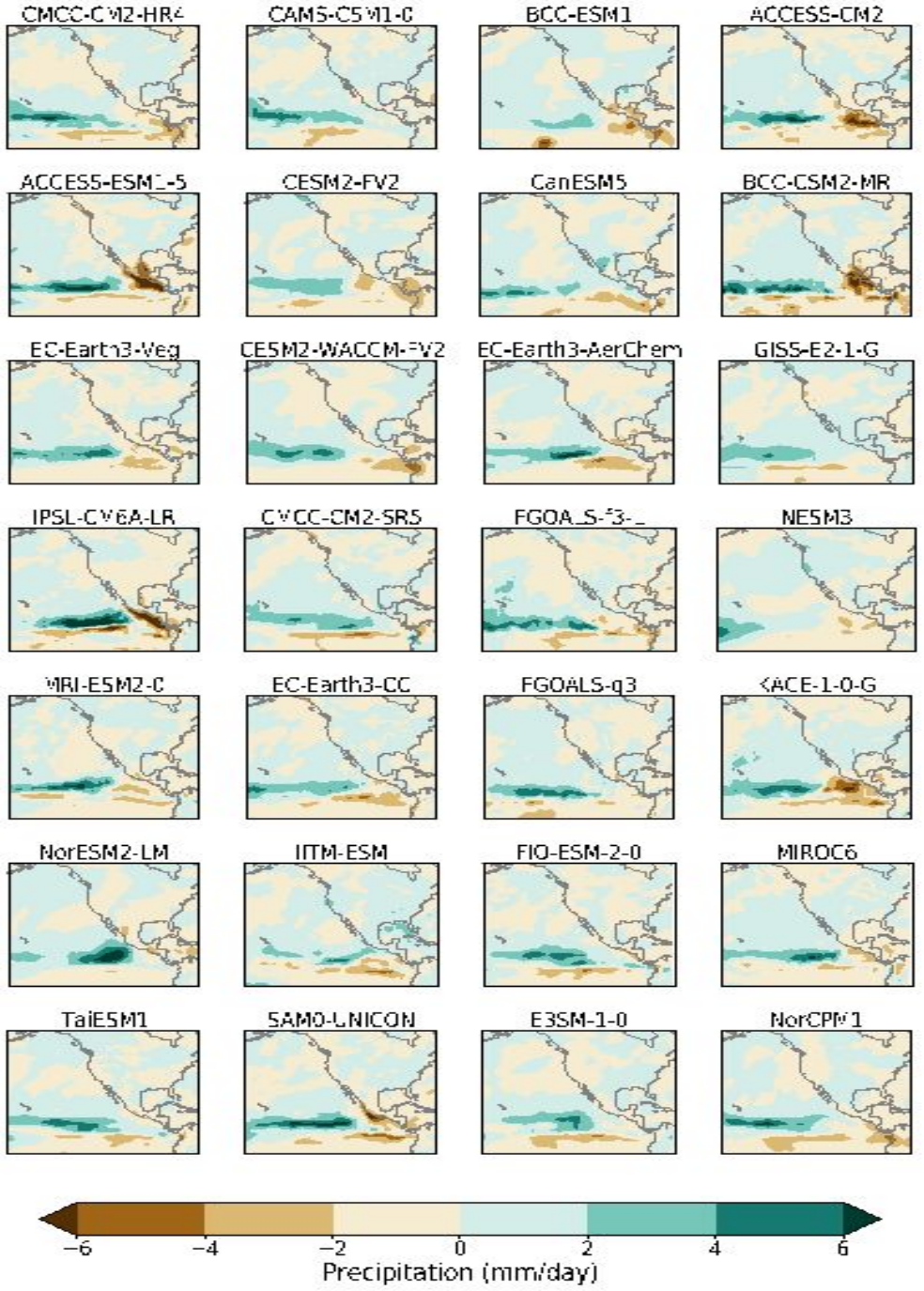
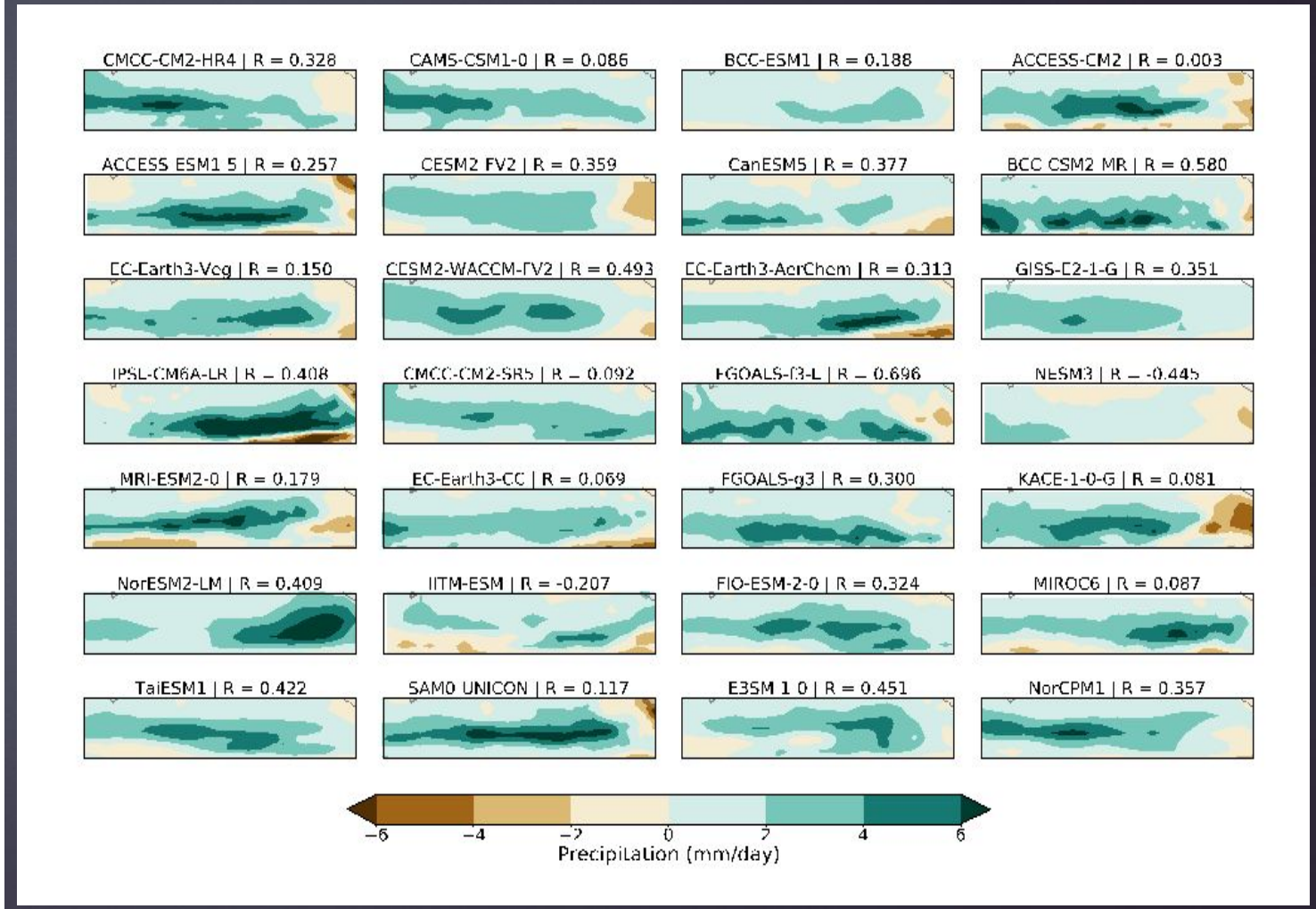

(a) Temperature
47°N
40°N
33°N
Latitude [°]
−1.0 −0.5 0.0 0.5 1.0 1.5 2.0
[° C]
(b) Precipitation
−1.2 −0.8 −0.4 0.0 0.4 0.8 1.2
[mm/day]
(c) Evapotranspiration
−12 −8 −4 0 4 8 12
[mm]
(a) Correlations: ET & T = -0.170 ; ET & P = 0.658
Evapo-transpiration [mm]
Temperature [° C]
2020-01 2020-04 2020-07 2020-10 2021-01 2021-04 2021-07 2021-10 2022-01
Evapo-transpiration (ET)
Temperature (T)
Precipitation (P)
(e) Soil Moisture
120°W
112°W
105°W
Longitude [°]
−60 −40 −20 0 20 40 60
[mm]


CMCC-CM2-HR4
CAM5-CSM1-0
BCC-ESM1
ACCESS-CM2
ACCESS-ESM1-5
CESM2-FV2
CanESM5
BCC-CSM2-MR
EC-Earth3-Veg
CESM2-WACCM-FV2
EC-Earth3-AerChem
GISS-E2-1-G
IPSL-CM6A-LR
CMCC-CM2-SR5
FGOALS-g3
NESM3
MRI-ESM2-0
EC-Earth3-CC
FGOALS-g3
KACE-1-0-G
NorESM2-LM
IITM-ESM
FIO-ESM-2-0
MIROC6
TaiESM1
SAM0-UNICON
E3SM-1-0
NorCPM1
−6
−4
−2
0
2
4
6
Precipitation (mm/day)


CMCC-CM2-HR4 | R = 0.328
CAM5-CSM1-0 | R = 0.086
BCC-ESM1 | R = 0.188
ACCESS-CM2 | R = 0.003
ACCESS ESM1 5 | R = 0.257
CESM2 FV2 | R = 0.359
CanESM5 | R = 0.377
BCC CSM2 MR | R = 0.580
EC-Earth3-Veg | R = 0.150
CESM2-WACCM-FV2 | R = 0.493
EC-Earth3-AerChem | R = 0.313
GISS-E2-1-G | R = 0.351
IPSL-CM6A-LR | R = 0.408
CMCC-CM2-SR5 | R = 0.092
FGOALS-G3-L | R = 0.696
NESM3 | R = -0.445
MRI-ESM2-0 | R = 0.179
EC-Earth3-CC | R = 0.069
FGOALS-g3 | R = 0.300
KACE-1-0-G | R = 0.081
NorESM2-LM | R = 0.409
IITM-ESM | R = -0.207
FIO-ESM-2-0 | R = 0.324
MIROC6 | R = 0.087
TaiESM1 | R = 0.422
SAM0 UNICON | R = 0.117
E3SM 1 0 | R = 0.451
NorCPM1 | R = 0.357
−6
−4
−2
0
2
4
6
Precipitation (mm/day)