

Supplementary Materials for

Trends in atmospheric patterns conducive to seasonal precipitation and temperature extremes in California

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Supplementary Materials

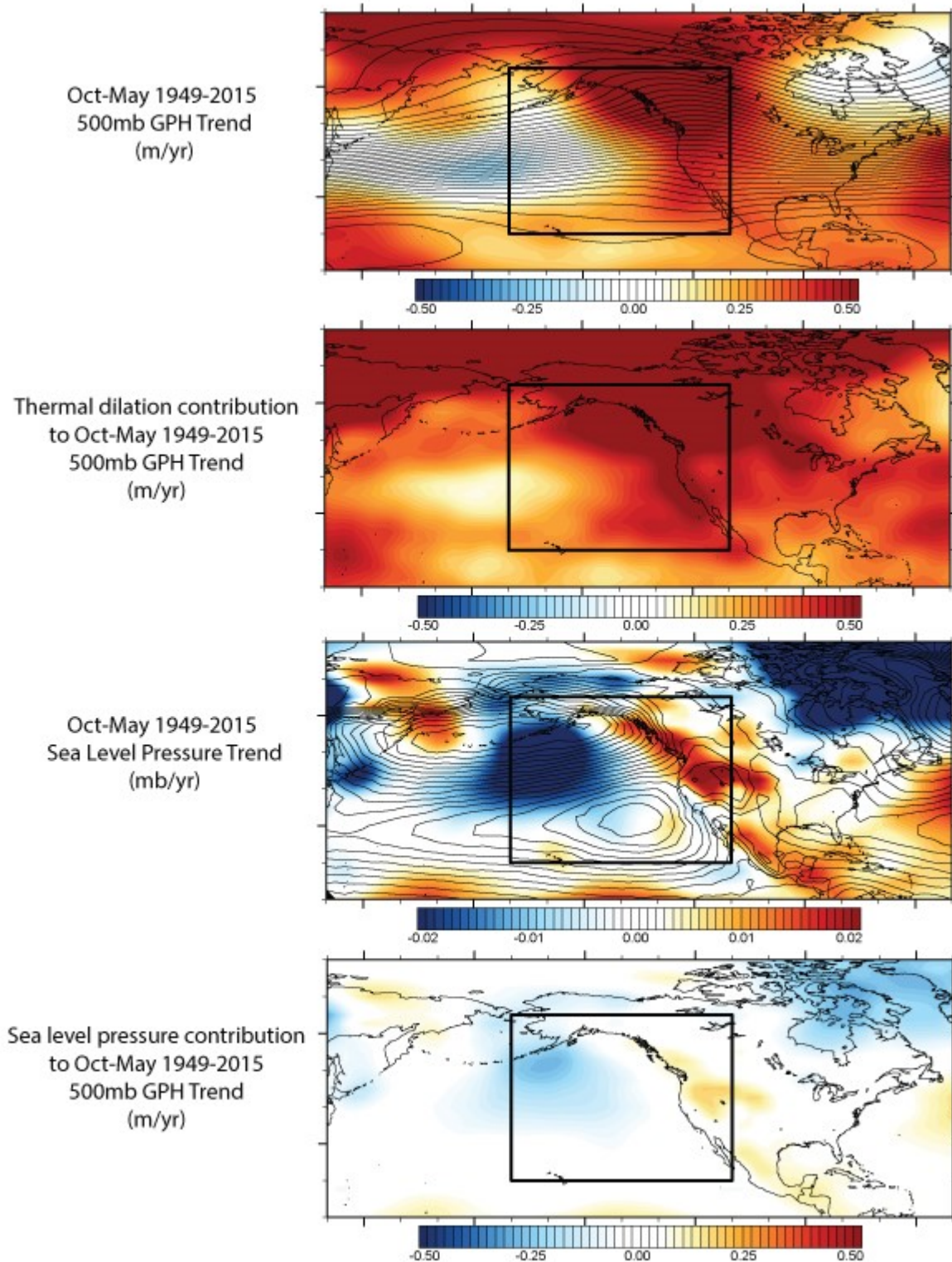


fig. S1. Observed October-May changes across the northeastern Pacific. **A.** Mean trend in October-May 500mb GPH over the northeastern Pacific and western North America, 1949-2015 (meters/year). Black box in A-C depicts the North Pacific Domain (NPD). **B.** Contribution of lower tropospheric warming (thermal dilation) to observed October-May GPH trend (meters/year) **C.** Mean trend in October-May SLP over the northeastern Pacific and western North America, 1949-2015 (millibars/year). **D.** Contribution of SLP (dynamical) trends to observed October-May GPH trend (meters/year).

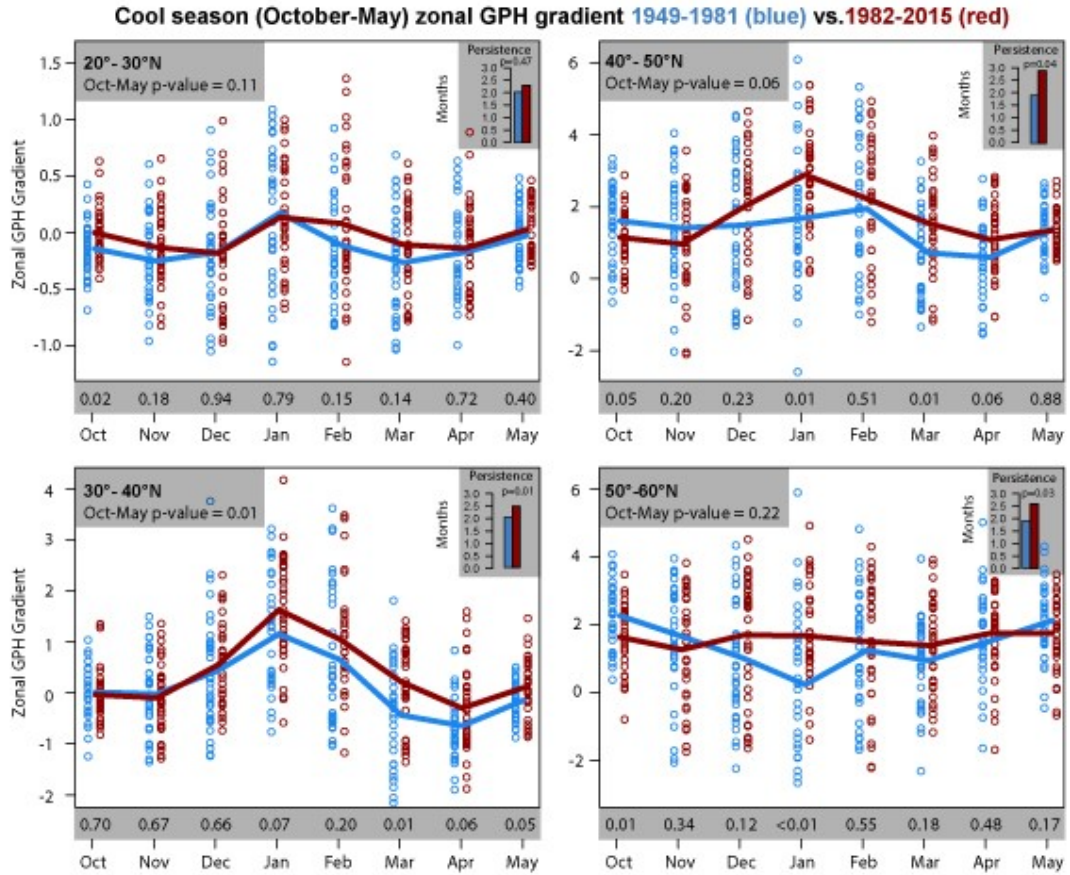


fig. S2. Observed October-May changes in zonal GPH gradient over the northeastern Pacific. Blue (red) points represent monthly values of the west-to-east GPH gradient averaged over the given range of latitudes from each year 1949-1981 (1982-2015). Blue (red) curves represent monthly values of the west-to-east GPH gradient averaged over the given range of latitudes, averaged over 1949-1981 (1982-2015). The insets in the upper right of each box show the change in sub-seasonal persistence of GPH gradients above the long term average (months/year). Blue (red) columns represent mean values for 1949-1981 (1982-2015).

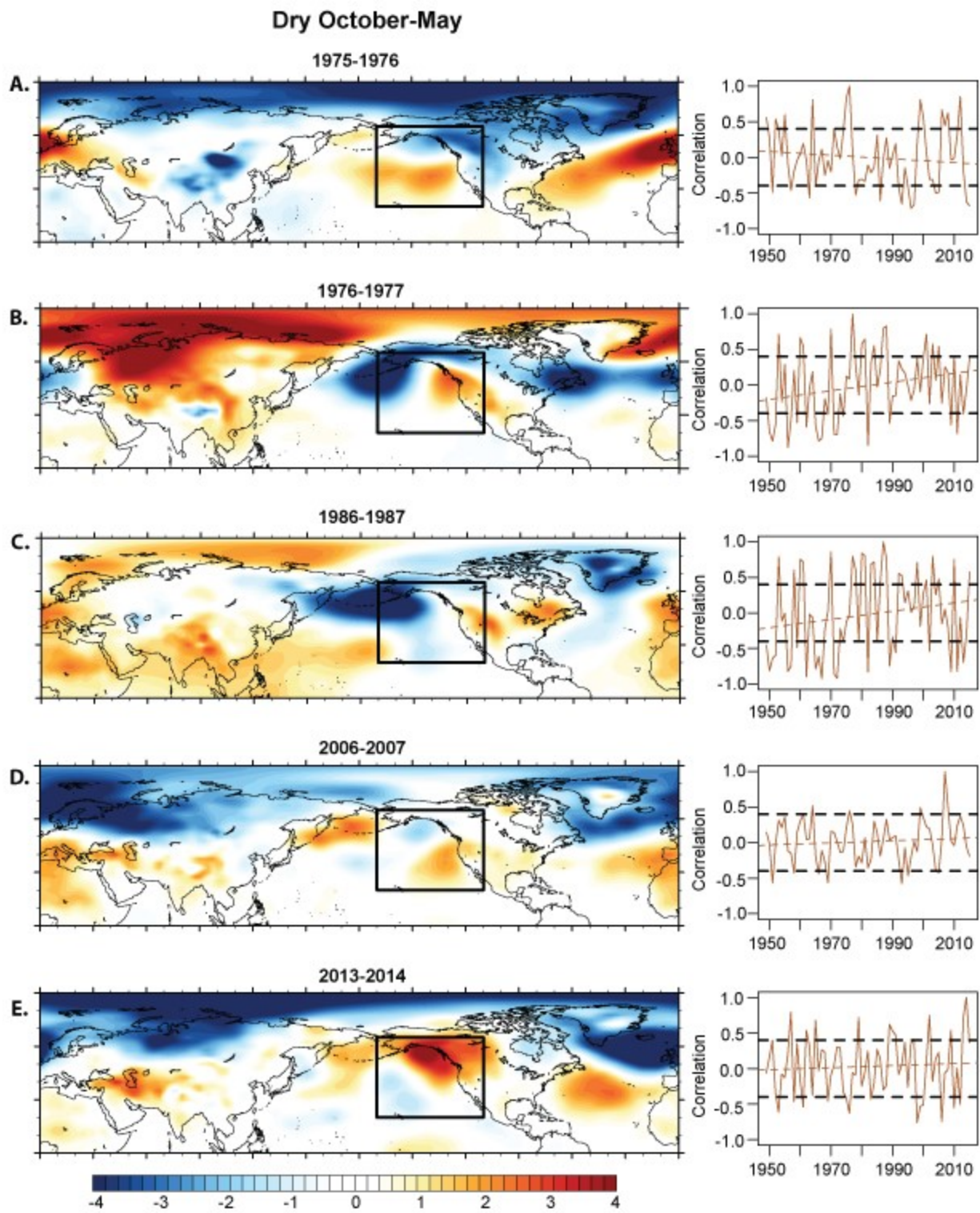


fig. S3. Trends in California extreme dry patterns. October-May SLP anomaly patterns during California’s 5 driest cool-season periods between 1949-2015 (left column) and timeseries of pattern correlation between SLP in each specific year of interest (right column) and all other years. Horizontal dashed black lines highlight ± 0.4 correlation thresholds used to define “moderate to high correlation” in the manuscript.

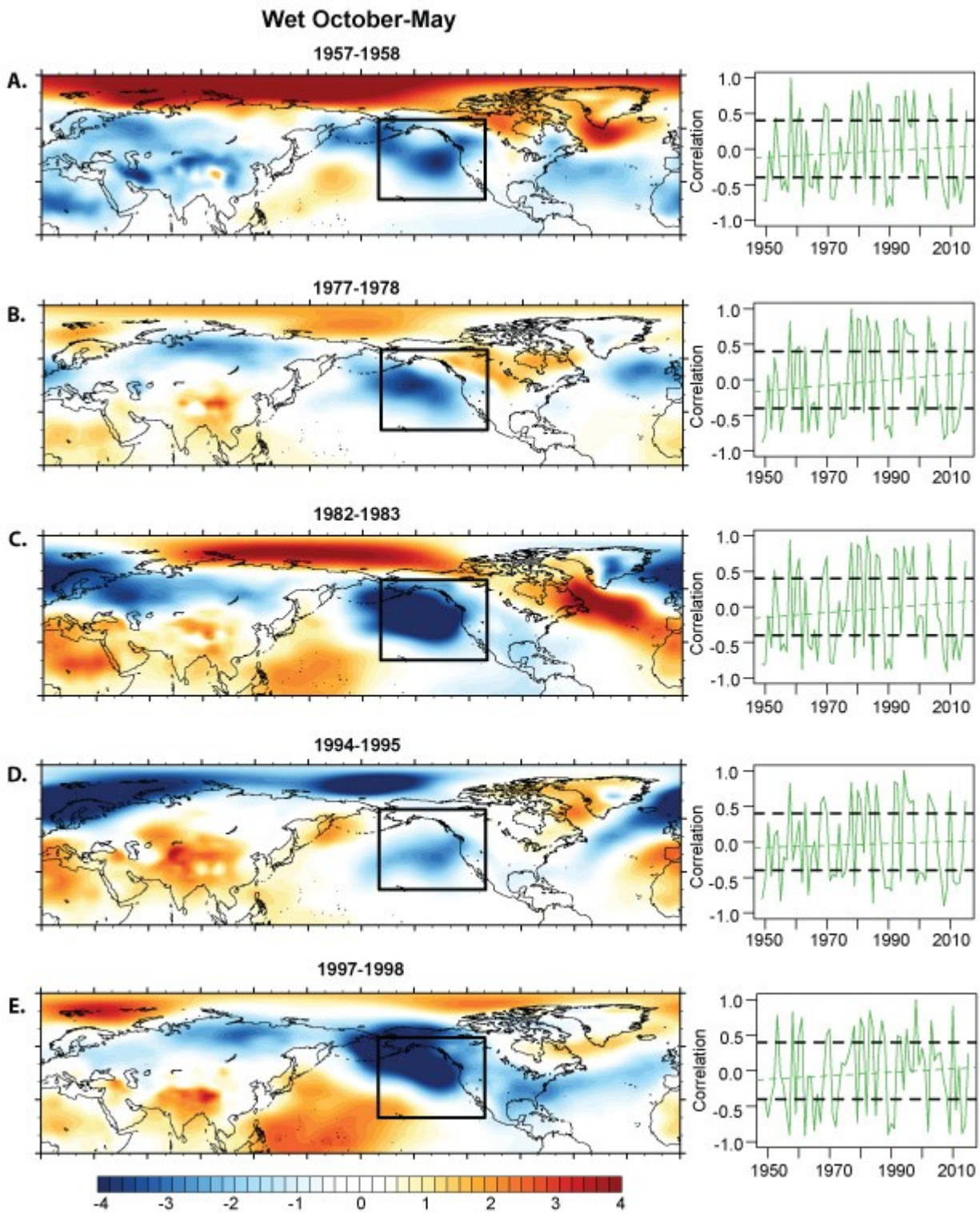


fig. S4. Trends in California extreme wet patterns. October-May SLP anomaly patterns during California’s 5 wettest cool-season periods between 1949-2015 (left column) and timeseries of pattern correlation between SLP in each specific year of interest (right column) and all other years. Horizontal dashed black lines highlight ± 0.4 correlation thresholds used to define “moderate to high correlation” in the manuscript.

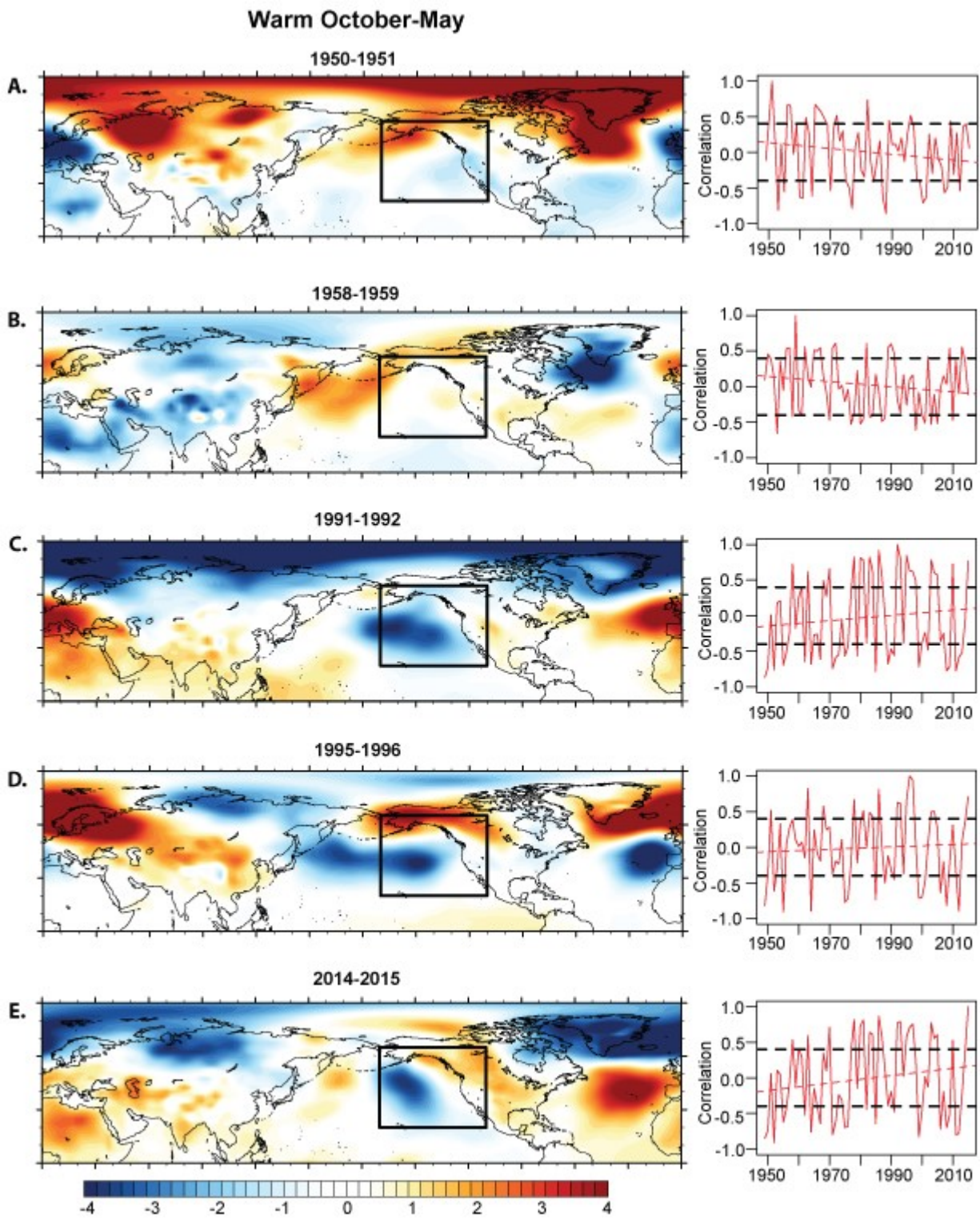


fig. S5. Trends in California extreme warm patterns. October-May SLP anomaly patterns during California’s 5 warmest de-trended cool-season periods between 1949-2015 (left column) and timeseries of pattern correlation between SLP in each specific year of interest (right column) and all other years. Horizontal dashed black lines highlight ± 0.4 correlation thresholds used to define “moderate to high correlation” in the manuscript.

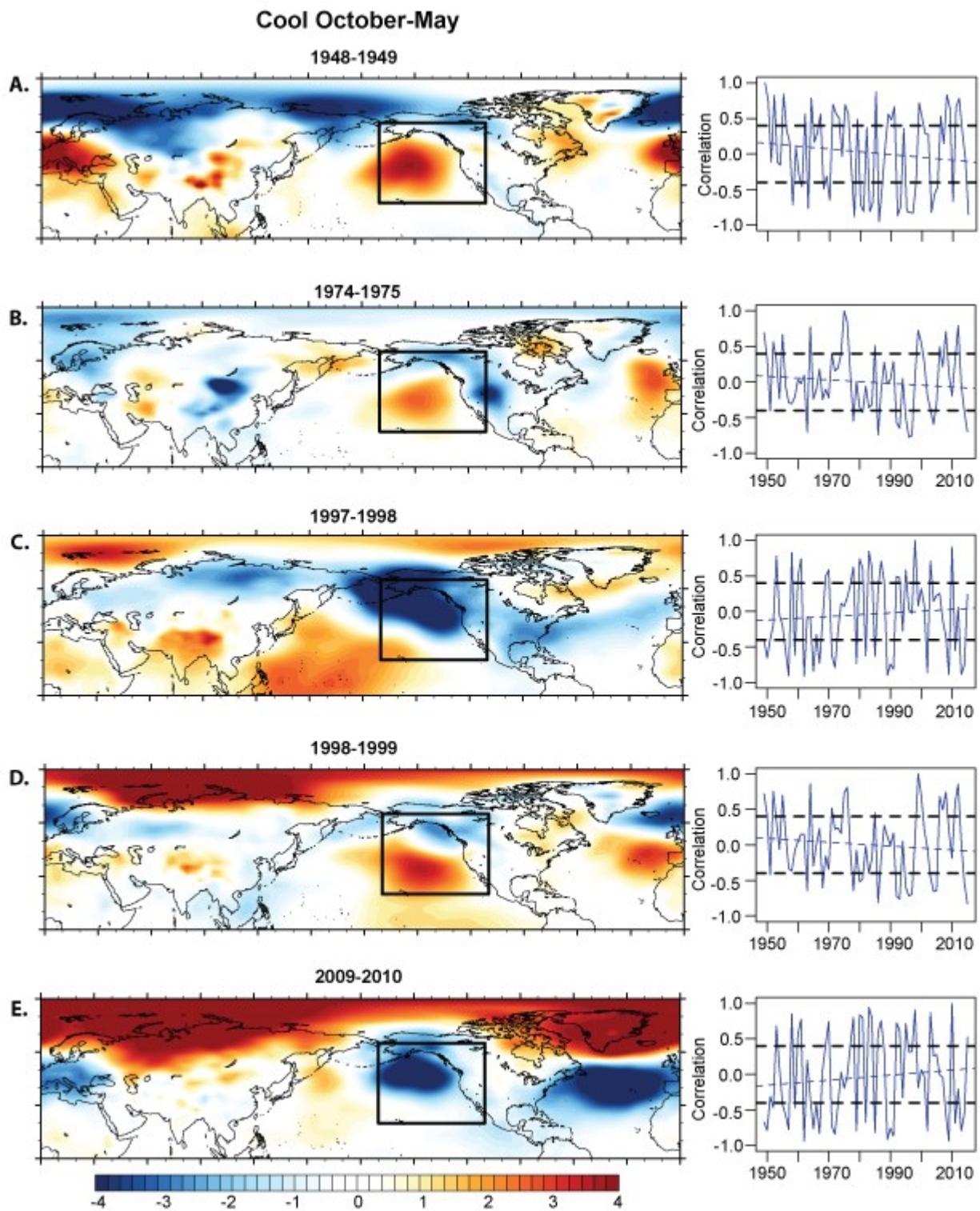


fig. S6. Trends in California extreme cool patterns. October-May SLP anomaly patterns during California’s 5 coolest de-trended cool-season periods between 1949-2015 (left column) and timeseries of pattern correlation between SLP in each specific year of interest (right column) and all other years. Horizontal dashed black lines highlight ± 0.4 correlation thresholds used to define “moderate to high correlation” in the manuscript.

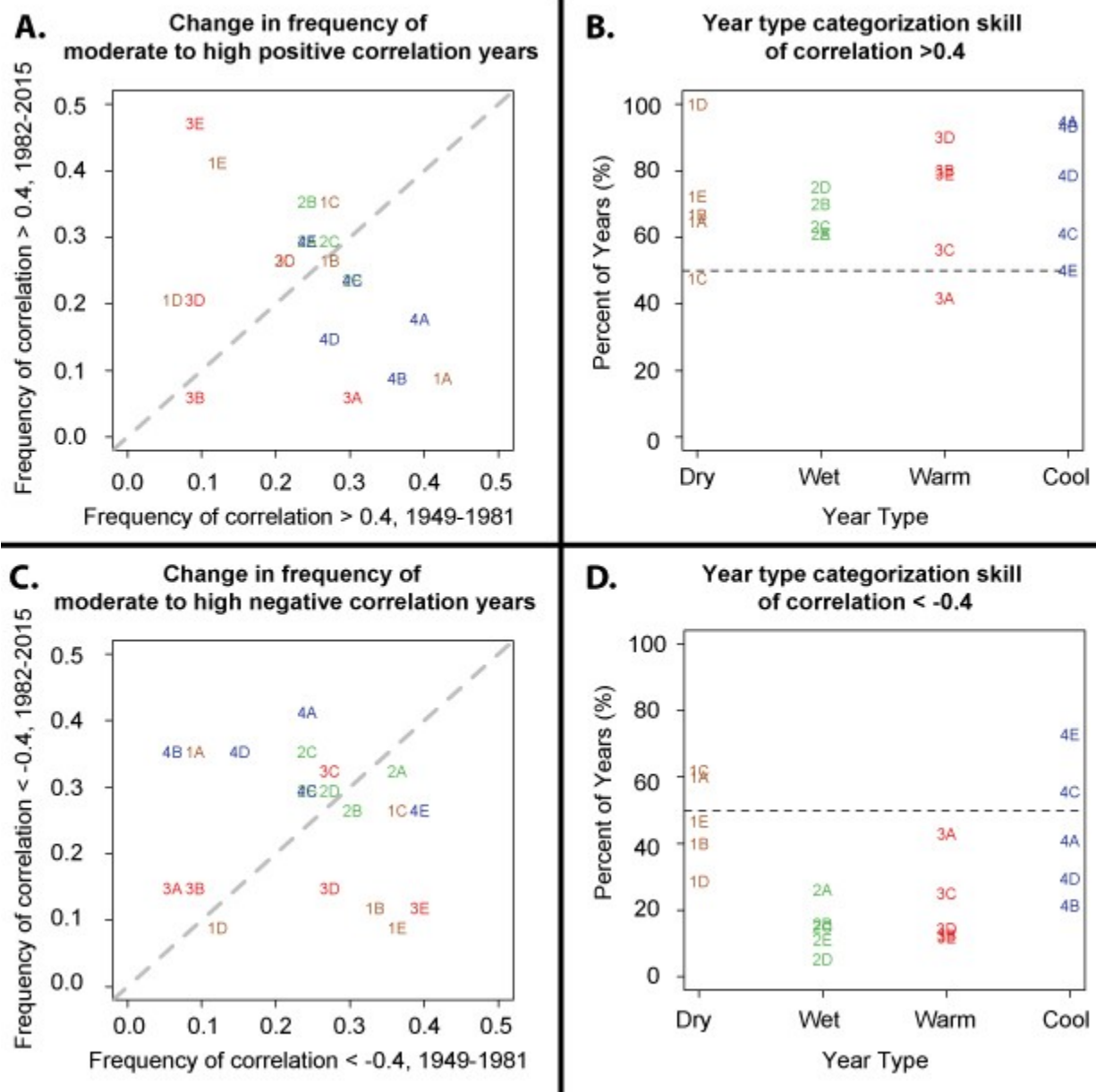


fig. S7. Change in frequency of high-correlation years using GPH. **A.** Change in frequency of moderate-to-high correlation years (correlation > 0.4) between 1949-1981 and 1982-2015. Points above the dashed 1:1 line imply increasing frequency; points below 1:1 line imply decreasing frequency. **B.** Percent of years with pattern correlation > 0.4 with specific extreme pattern that experienced surface meteorological conditions of the correct sign (e.g., below-average precipitation in a year with high correlation with the 2013-2014 pattern). **C.** Same as A, except for correlation < -0.4. **D.** Same as B, except for correlation < -0.4. In all panels, point labels correspond to figure panel labels in figs. S3-S6, and are also color coded by year type (brown/"1" = dry; green/"2" = wet; red/"3" = warm; blue/"4" = cool).

	Dry		Wet		Warm		Cool	
	DT	NDT	DT	NDT	DT	NDT	DT	NDT
	1975 - 1976		1957 - 1958		1950 - 1951		1948 - 1949	
Mag	- 0.54 ↓	- 1.21 ↓	+ 0.57 ↑	+ 0.25 ↑	- 0.36 ↓	- 0.85 ↓	- 0.58 ↓	- 0.81 ↓
P-Val	0.07	< 0.01	0.10	0.48	0.16	< 0.01	0.10	0.01
	1976 - 1977		1977 - 1978		1958 - 1959		1974 - 1975	
Mag	+ 0.64 ↑	+ 0.54 —	+ 0.36 ↑	- 0.18 ↑	- 0.22 ↑	- 0.01 ↓	- 0.42 ↓	- 0.99 ↓
P-Val	0.04	0.08	0.30	0.60	0.37	0.97	0.14	< 0.01
	1986 - 1987		1982 - 1983		1991 - 1992		1997 - 1998	
Mag	+ 0.60 ↑	+ 0.43 ↑	+ 0.25 ↑	- 0.42 —	+ 0.48 ↑	+ 0.16 ↑	+ 0.18 —	- 0.23 ↓
P-Val	0.10	0.23	0.46	0.22	0.11	0.59	0.59	0.49
	2006 - 2007		1994 - 1995		1995 - 1996		1998 - 1999	
Mag	+ 0.01 ↓	+ 0.68 ↑	+ 0.29 ↑	- 0.09 ↑	+ 0.22 ↑	+ 0.39 ↑	- 0.49 ↓	- 0.41 ↓
P-Val	0.98	< 0.01	0.34	0.77	0.40	0.13	0.11	0.16
	2013 - 2014		1997 - 1998		2014 - 2015		2009 - 2010	
Mag	+ 0.34 ↑	+ 1.06 ↑	+ 0.18 —	- 0.23 ↓	+ 0.71 ↑	+ 1.29 ↑	+ 0.34 ↑	+ 0.22 ↑
P-Val	0.26	< 0.01	0.59	0.49	0.03	< 0.01	0.34	0.54

fig. S8. A comprehensive summary of extreme pattern trend results for analysis using linearly detrended 500-mb GPH data (columns labeled “DT”) and using non-detrended GPH data (columns labeled “NDT”). Rows labeled “Mag” report the magnitude of the mean linear trend in pattern correlation with the pattern associated with a particular year; rows labeled “P-Val” report the magnitude of the p-value associated with confidence in the linear regression used to calculate the mean trends. Upward (downward) facing arrows indicate the sign of the change between 1949-1981 and 1982-2015 of years with moderate to high (>0.4) pattern correlation with the pattern observed in a given year. Horizontal bars in place of arrows denote little change (<10%) in pattern occurrence between the two periods.

Pattern correlation timeseries for de-trended GPH

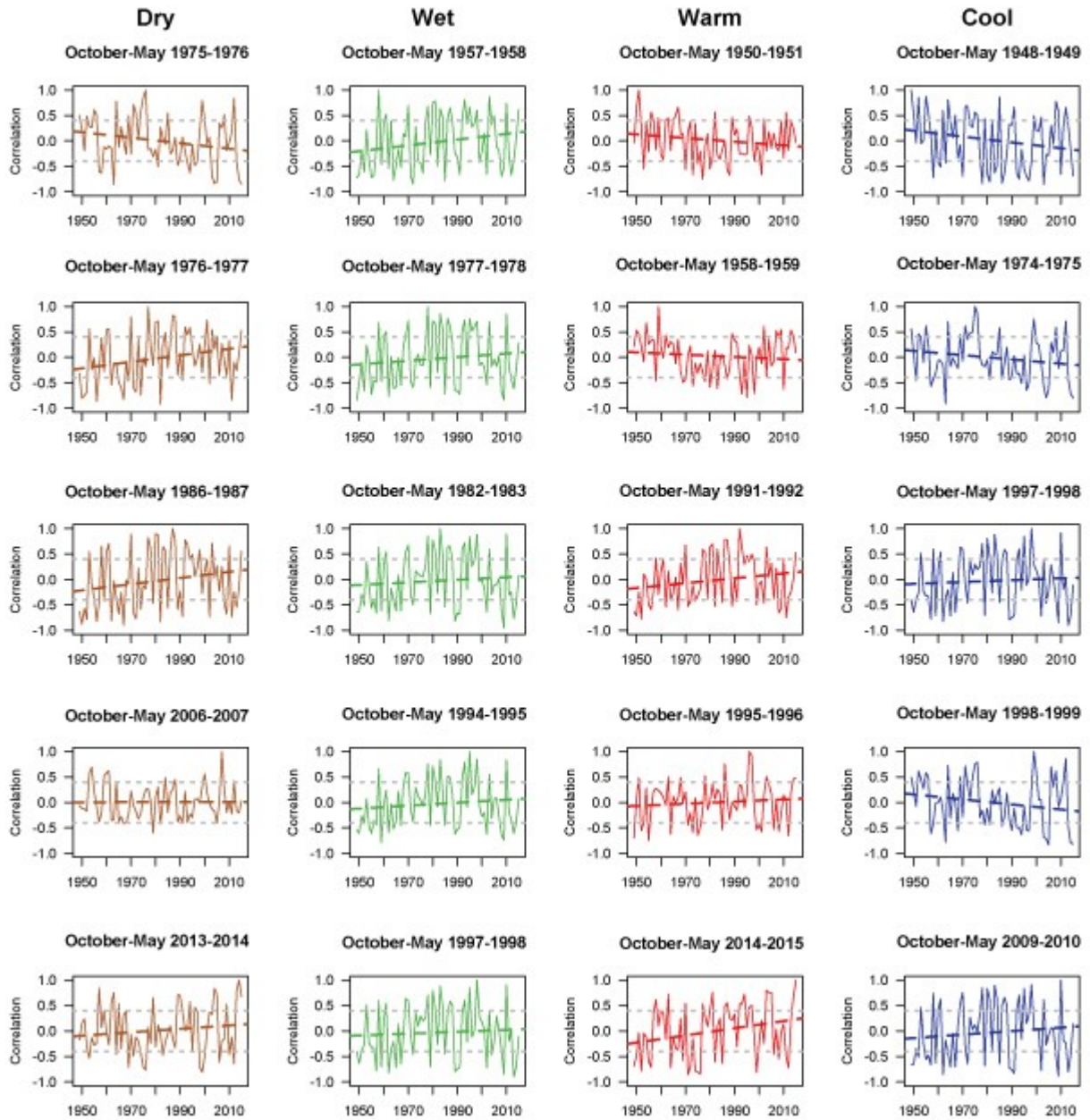


fig. S9. Time series of pattern correlation between GPH pattern in each specific year of interest and all other years using linearly detrended GPH data. Heavy dashed lines show linear mean trend in pattern correlation, and horizontal dashed grey lines highlight ± 0.4 correlation thresholds used to define “moderate to high correlation” in the manuscript. From left to right, columns refer to dry, wet, warm, and cool pattern trends, respectively.

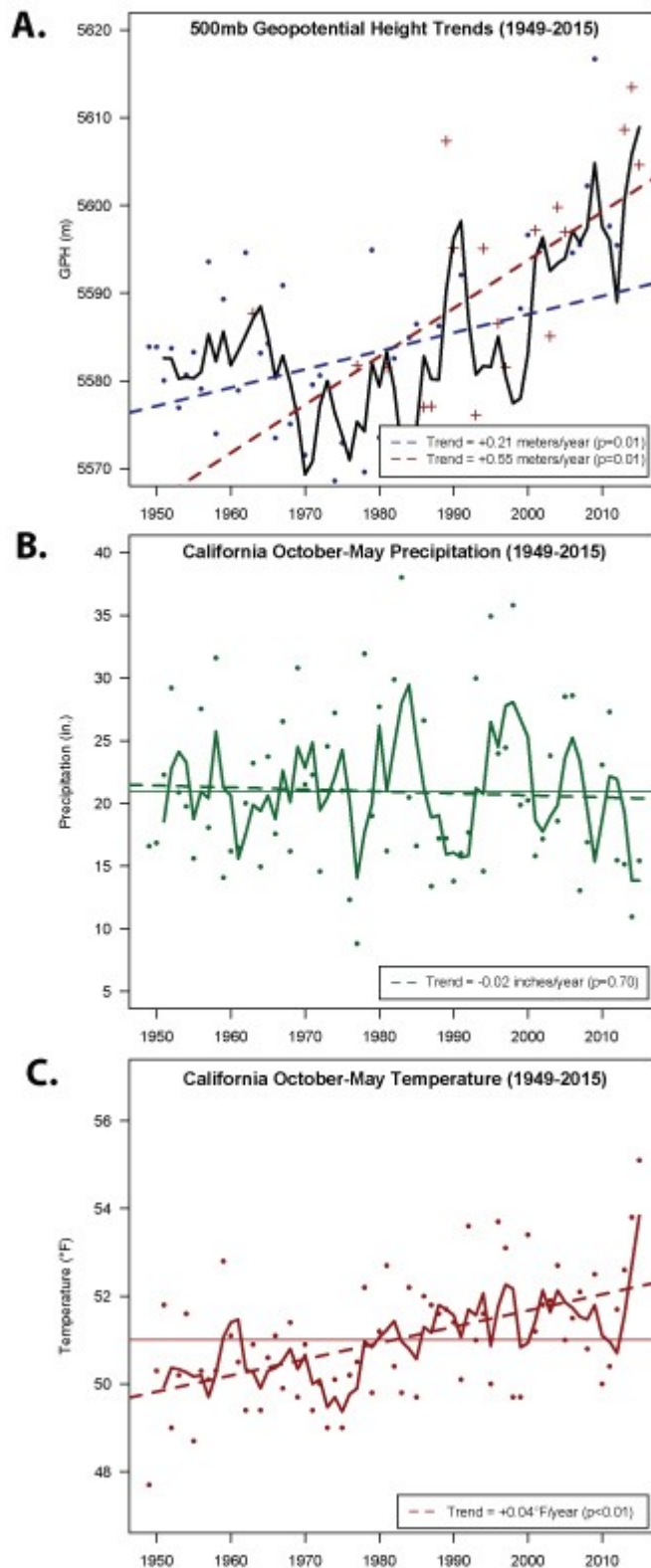


fig. S10. Observed trends in GPH, precipitation, and temperature. A. Timeseries of October-May NPD 500mb GPH (m). Blue (red) dots denote values during years with pattern correlations ≤ 0.4 (≥ 0.4) relative to the 2014-2015 pattern. Blue (red) dashed lines represent the linear regression line for years with pattern correlation ≤ 0.4 (≥ 0.4). Blue circles (red crosses) depict values in individual years with correlation ≤ 0.4 (≥ 0.4). Solid black curve depicts the (right-sided) 3-year running mean GPH. **B.** Timeseries of October-May NPD California precipitation

(inches). Solid green curve depicts the (right-sided) 3-year running mean precipitation. **C.** Timeseries of October-May NPD California temperature (degrees F). Solid brown curve depicts the (right-sided) 3-year running mean temperature.