Supporting Information for
"Removing Circulation Effects to Assess Central US Land-Atmosphere Interactions in the CESM Large Ensemble"

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S1. Dynamical Adjustment using Constructed Circulation Analogs

The dynamical adjustment technique used in the study was developed to evaluate the contribution of internal atmospheric variability to North American SAT trends in the CESM-LE and in observations [*Deser et al.*, 2016; *Lehner et al.*, 2017]. The method draws on the principles that underpin numerical weather prediction [*Lorenz*, 1969; *van den Dool*, 1994; *van den Dool et al.*, 2003] and statistical downscaling [*Zorita et al.*, 1995], leveraging the relationship between large-scale circulation patterns and local SAT variability. In *Deser et al.* [2016], the SLP field is used to represent large-scale circulation. Here, the Z500 field is used. Otherwise, the methods are identical.

We select "analogues" of the large-scale circulation pattern in Z500 for a target month, i.e. July 1920 in CESM-LE run 1, from a set of potential candidates. In this case, the set of potential candidates are the July Z500 fields in an 1800-year CESM simulation with a constant preindustrial forcing (PiCTL) [*Kay et al.*, 2015]. To find analogues, each of the 1800 candidates are ranked according spatial similarity with the target Z500 field over the domain 20-90°N, 180-10°W. Similarity is defined as the shortest Euclidean distance between the target and candidate at each gridpoint. The 150 ($\mathbf{N}_a$ in *Deser et al.* [2016]) most similar candidates comprise a set of Z500 analogues. From that set, 100 ($\mathbf{N}_s$ in *Deser et al.* [2016]) Z500 analogues are selected and configured in an $m \times 100$ column matrix, $\mathbf{X}_c$, where m is the number of gridpoint in the domain. $\mathbf{X}_c$ is used to find an opti-

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mal linear reconstruction, $\mathbf{X}_{ca}$, of the target Z500 field as:

$$X_{ca} = X_c \cdot \beta, \tag{1}$$

β is a vector containing the optimal contribution of each Z500 analogue to $\mathbf{X}_{ca}$; its elements are computed from a singular value decomposition of $\mathbf{X}_c$. β is then used to weight the SAT patterns in the PiCTL that co-occur with each Z500 analogue. This provides an estimate of circulation-induced SAT. The process is then repeated to obtain 100 ($\mathbf{N}_r$ in *Deser et al.* [2016]) estimates of circulation-induced SAT. The dynamic component of SAT used in this study is the average of those 100 estimates. Because the dynamic component of SAT is sensitive to the choice of $\mathbf{N}_s$ and $\mathbf{N}_r$, we have chosen parameters that ensure convergence as illustrated in the appendix of *Deser et al.* [2016].

S2. Additional Technical Details

In Figure 1, the two cases were selected based on the spatial structure of July Z500 EOF1 computed over the domain 20-65°N, 170-50°W. The Julys selected were representative of the Z500 spatial mode and had similar Z500 structure "upstream" of the continental US. The SAT anomaly field (anomaly from the 1920-2005, historical period average) in all Julys that met those Z500 criteria were considered, and two that had similar dynamic components (Figure 1 C,D), but different total SAT (Figure 1 A,B) were selected.

In Figure 2c, the level of 95% significance (gray dashed line) was determined through a bootstrapping approach [*DiCiccio and Efron*, 1996]. The timeseries of each month's hotspot SAT is randomly sampled (without replacement) and correlated with the timeseries of August hotspot SAT. This is repeated 1000 times for each of the 30 members, generating a distribution of 30,000 correlation coefficients. The distribution is then sorted and divided into quantiles. Correlations exceeding the lower bound of the 95th percentile are considered distinguishable from zero. The method is repeated for each month, and the twelve 95% significance levels were averaged to obtain a lower bound of r = 0.18. A similar method was used in Figure 3, with the 2580 model-year timeseries of JJA hotspot SAT correlated with the soil moisture timeseries at each grid point, repeated 100 times. The threshold of 95% significance cited in the text, r = 0.03, reflects the average value over the central US domain shown in the figure, 24-48°N, 106-80°W. In both cases, the bootstrap-derived 95% significance thresholds are equivalent to those determine by Student's T-test.

In Figure 2d, the spectra were computed using Fast Fourier Transforms of the untapered JJA hotspot SAT timeseries'. The spectral densities of each ensemble member were smoothed in frequency domain using a three-point Hanning window. The solid line shows the average over the ensemble and the shading shows the spread ($\pm 1\sigma$) of the ensemble spectral densities about the mean.

References

Deser, C. A., L. Terray, and A. S. Phillips (2016), Forced and internal components of winter air temperature trends over North America during the past 50 years: Mechanisms and implications, *J. Climate*, *29*, 2237–2258, doi:10.1175/JCLI-D-15-0304.1.

DiCiccio, T. J., and B. Efron (1996), Bootstrap Confidence Intervals, *Statistical Science*, *11*, 189–228.

Kay, J. E., C. Deser, A. Phillips, A. Mai, C. Hannay, G. Strand, J. Arblaster, S. Bates, G. Danabasoglu, J. Edwards, M. Holland, P. Kushner, J. F. Lamarque, D. Lawrence, K. Lindsay, A. Middleton, E. Munoz, R. Neale, K. Oleson, L. Polvani, and M. Vertenstein (2015), The Community Earth System Model (CESM) Large Ensemble Project: A community resource for studying climate change in the presence of internal climate variability, *Bull. Amer. Met. Soc.*, *96*, 1333–1349, doi:10.1175/BAMS-D-13-00255.1.

Lehner, F., C. Deser, and L. Terray (2017), Towards a new estimate of "time of emergence" of anthropogenic warming: insights from dynamical adjustment and a large initial-condition model ensemble, *J. Climate*, doi:10.1175/JCLI-D-16-0792.1.

Lorenz, E. N. (1969), Atmospheric predictability as revealed by naturally occurring analogues, *Journal of the Atmospheric sciences*, *26*, 636–646.

van den Dool, H. M. (1994), Searching for analogues, how long must we wait?, *Tellus A*, *46*, 314–324, doi:10.1034/j.1600-0870.1994.t01-2-00006.x.

van den Dool, H. M., J. Huang, and Y. Fan (2003), Performance and analysis of the constructed analogue method applied to U.S. soil moisture over 1981-2001, *J. Geophys. Res.*, *108*, 8617, doi:10.1029/2002JD003114.

Zorita, E. J. P., D. P. Lettenmaier, and H. von Storch (1995), Stochastic characterization of regional circulation patterns for climate model diagnosis and estimation of local precipitation, *J. Climate*, *8*, 1023–1042, doi:10.1175/1520-0442(1995)008,1023:SCORCP.2.0.CO;2.