Supplemental Material

Supplementary Material to

Toward a New Estimate of "Time of Emergence" of Anthropogenic Warming: Insights from Dynamical Adjustment and a Large Initial-Condition Model Ensemble

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Content

Choice of data pool to choose circulation analogues from

The dynamical adjustment with atmospheric circulation analogues as carried out in this study makes an assumption of stationarity regarding the relationship between an SLP pattern and the associated SAT anomalies. It does so in that it chooses circulation analogues from a preindustrial control simulation, which by design includes no forced climate change. To test whether this assumption has a significant influence on the outcome of our analysis, we repeat the dynamical adjustment (and subsequent ToE calculation) for the first 10 CESM LE members, but this time we choose circulation analogues from the historical (1920-2009) part of the CESM LE itself rather than from the preindustrial control simulation. Specifically, we detrend SAT from CESM LE members 11 to 30 by subtracting the CESM LE ensemble mean at each grid point and concatenate them to form a "pseudo control simulation" of 1800-year length (equal to the preindustrial control simulation). We also adjust the long term mean of this pseudo control simulation at each grid point to match the one of the preindustrial control simulation. Similarly, we concatenate SLP from the same 20 ensemble members (without detrending) to form a pseudo control simulation, also adjusting the mean. We then repeat the dynamical adjustment using these pseudo control simulations of SLP and SAT to find circulation analogues. Large differences between the two dynamical adjustment calculation would point to a change in the relationship between SLP and SAT throughout the period 1920-2009 and possibly beyond. Fig. S1 shows the ToE calculated for the first 10 CESM LE members with the two approaches. There are differences between the two approaches, such as later ToE over northern North America and earlier ToE over Scandinavia, that might be related to a forced response in SLP, such as a strengthening of the Azores High. However, the differences in ToE are typically small, certainly in comparison to other sources of uncertainty discussed in this study.

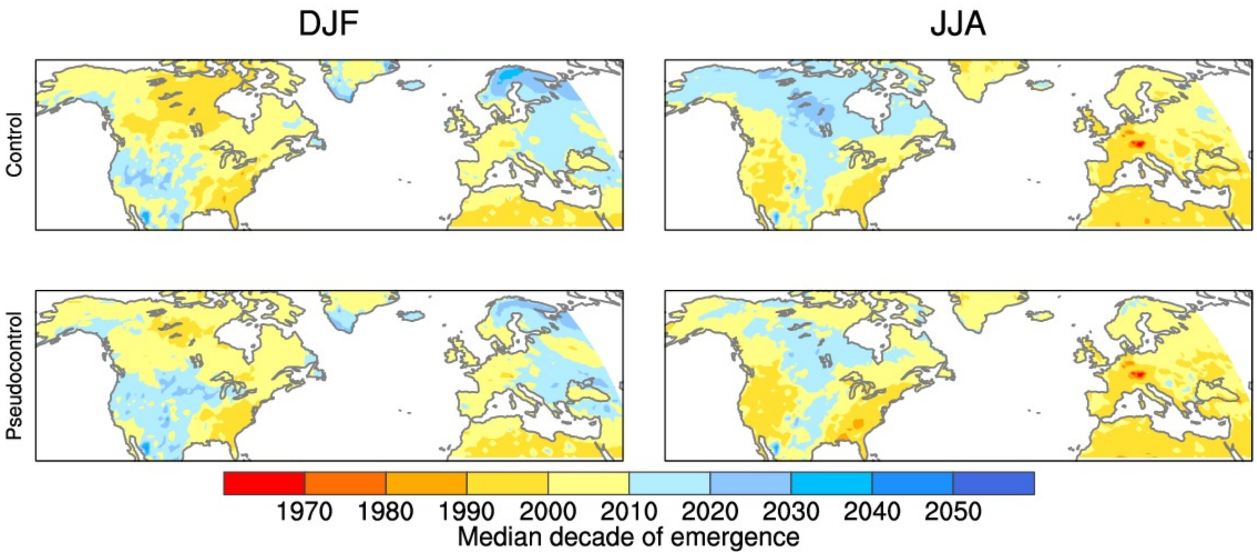

Figure S 1: Same as (b) and (d) in Figure 3 of the main text, but only for 10 CESM LE members and using (top) dynamically adjusted SAT from the preindustrial control and (bottom) from the concatenated historical part of the CESM LE ("pseudo control simulation").

Choice of running mean length

Fig. S2 shows an error metric for different running means applied to the data before conducting the time of emergence (ToE) analysis. The error indicates how accurate the estimate of ToE is, given that the observational record of surface air temperature (SAT) currently stops in 2015. This is tested within the CESM LE model world, where we know the evolution of SAT until 2100 and hence can calculate the actual ToE and then contrast it with the ToE using the model simulations until 2015 only. Fig. S2 illustrates that the error is reduced from 5- to 20-year running means with little additional error reduction afterwards. Fig. S2 also shows that in DJF for the 10-year running mean the error reduction achieved by the dynamical adjustment is as large as the error reduction from using a 20- instead of 10-year running mean.

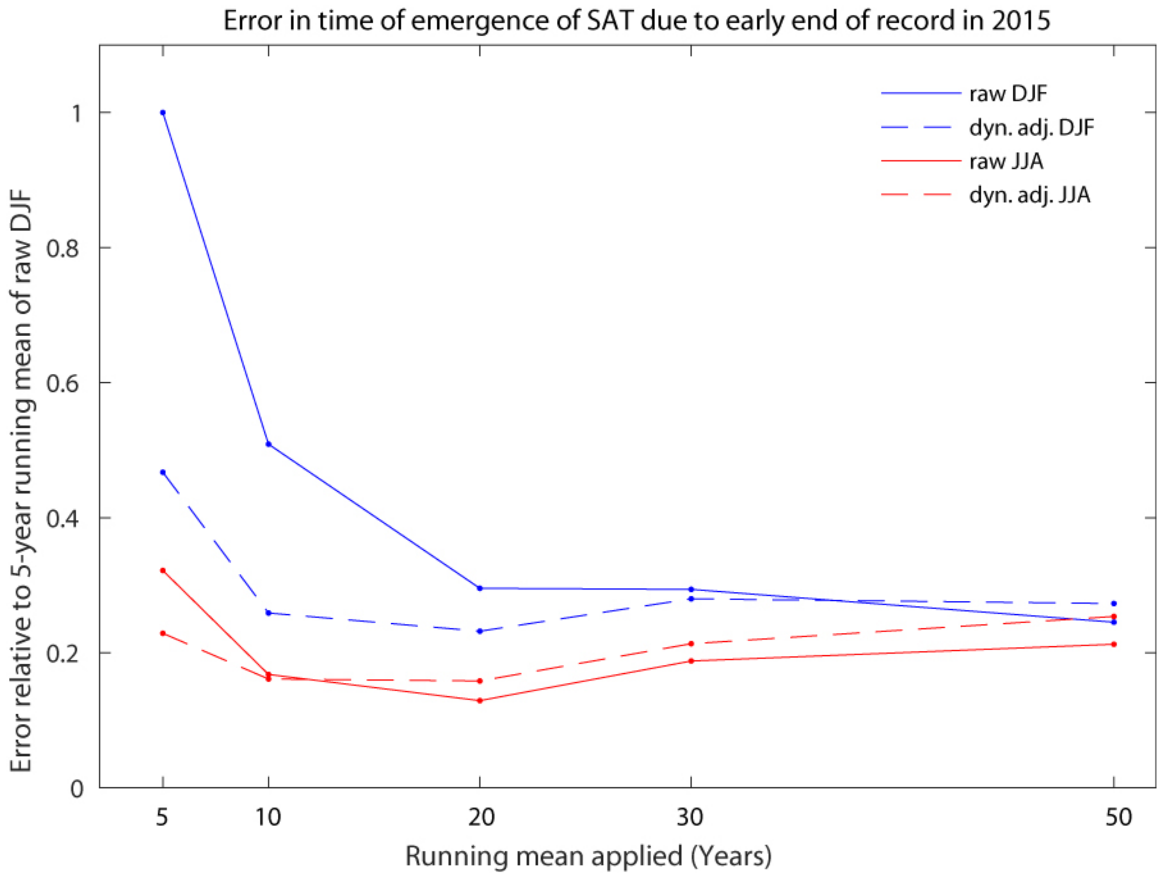

Figure S 2: Error in time of emergence calculated using the CESM LE simulations until 2015 and time of emergence calculated using the full CESM LE simulations until 2100, with 5-, 10-, 20-, 30-, and 50-year running mean applied, calculated separately for the raw and dynamically adjusted data. The error is calculated as follows. First, the difference in time of emergence using the full simulations until 2100 and the simulations until 2015 is calculated for each grid point (ΔToE). For a fair comparison, ΔToE is calculated only where emergence has occurred according to the 10-year running mean time series ending in 2015. Then, ΔToE at each grid point is summed across all CESM LE members, divided by the number of CESM LE members that showed emergence at that grid point, and then summed across North American and Europe. This yields a cumulative error in units of years. Finally, the error for both seasons is normalized by dividing by the error based on the raw data DJF. Note that for this analysis, the time of emergence threshold (2 standard deviations during the reference period 1920-1949) is derived from the concatenated reference periods of all CESM LE members. That is, for each running mean time series, the threshold used is the same for all CESM LE members.

Choice of observational dataset

Fig. S3 shows ToE calculated for different SAT datasets. Overall patterns are similar across datasets, although the exact ToE can differ, illustrating observational uncertainty in ToE estimates. Some differences might be related to how SAT variability is captured due to the different horizontal resolutions of the datasets.

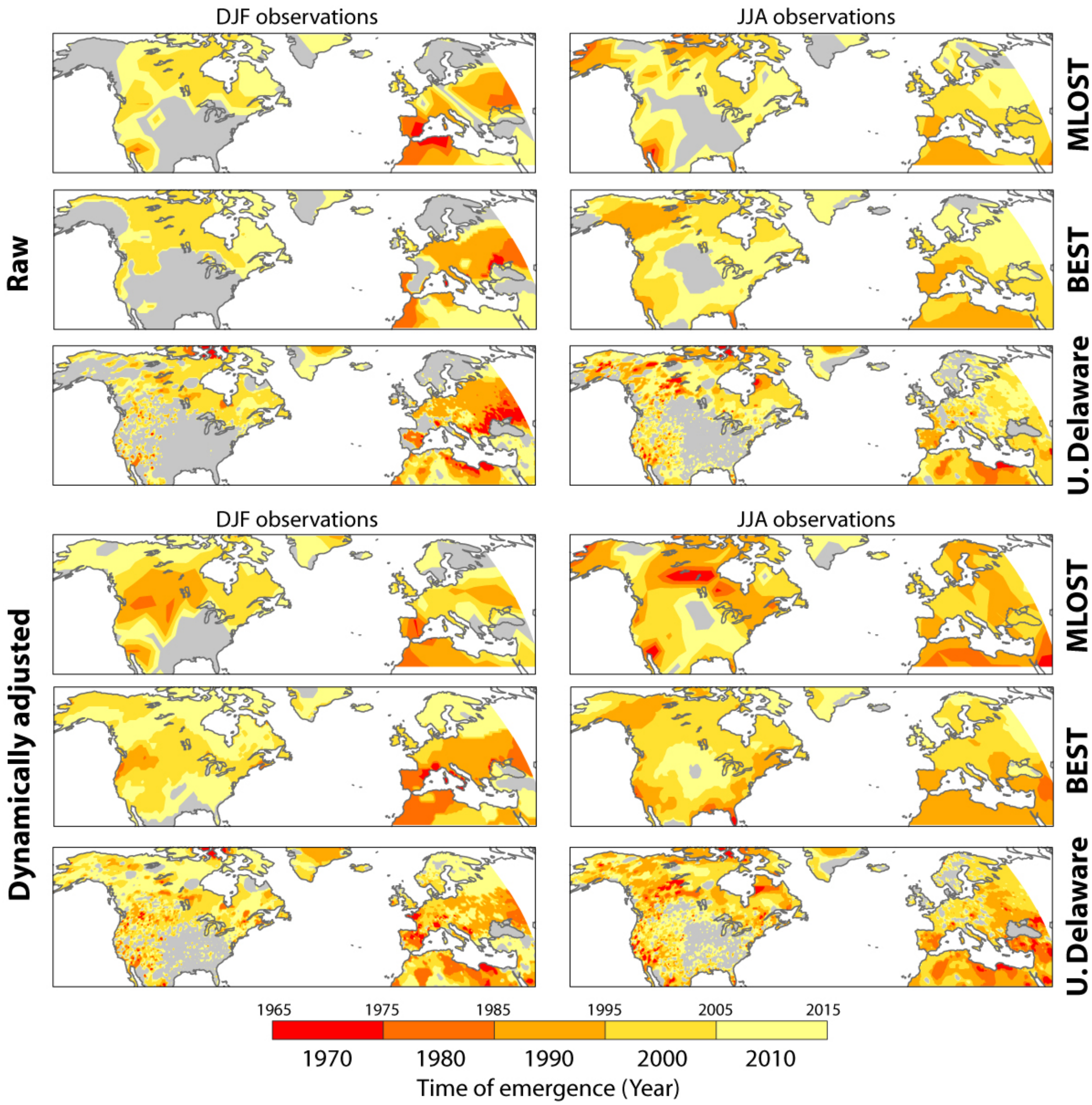

Figure S 3: Same as Figure 1 of the main text, but for two additional SAT datasets MLOST and University of Delaware. Panels for BEST are identical to Figure 1.

Alternative ToE calculation

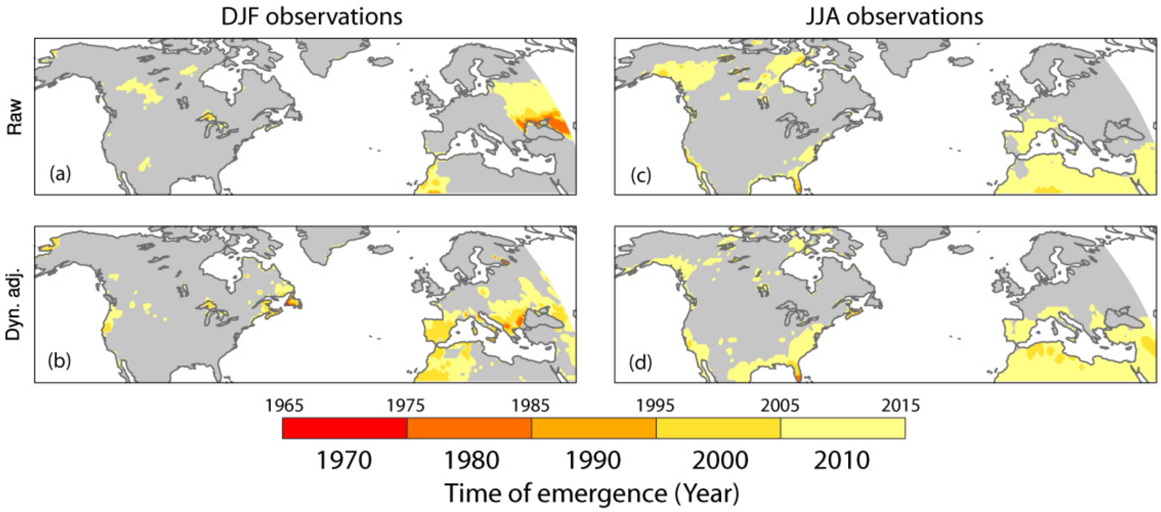

Figure S 4: Time of emergence of observed surface air temperature (BEST dataset) calculated as in Mahlstein et al. (2011) for DJF based on (a) raw and (b) dynamically-adjusted data. (c-d) Same as (a-b), but for JJA. Grey shading indicates where emergence has not yet occurred.

References

Mahlstein, I., R. Knutti, S. Solomon, and R. W. Portmann, 2011: Early onset of significant local warming in low latitude countries. *Environ. Res. Lett.*, **6**, 34009, doi:10.1088/1748-9326/6/3/034009.