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Statistical characteristics of extreme daily precipitation during 1501 BCE–1849 CE in the Community Earth System Model

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Empirical Orthogonal Function analysis (EOF; Hannachi et al., 2007) is used to derive the spatial patterns and the time series associated with the modes of internal variability in ERA5, CESM in 1979 – 2008 CE, and CESM during 1501 CE – 1849 CE. The EOF is applied to the sea surface temperature (SST) to infer the Pacific Decadal Oscillation (PDO) and the geopotential height at 500 hPa for other modes. The observational SST dataset is the ERSST v5 (Huang et al., 2017). The modes that are also detected as well by Fasullo et al. (2020) which used the CMIP models including the CESM family models, and by Lim (2015) which used the reanalysis are considered.

For the Northern Annular Mode (NAM; Thompson and Wallace, 2000) and Pacific North American (PNA) pattern (Wallace and Gutzler, 1981), the EOF is applied over the region confined to 180°W – 180°E and 20° – 90°N; for the Southern Annular Mode (SAM; Marshall, 2003) and the Pacific South American 1 (PSA) pattern (Mo and Paegle, 2001), the region over 180°W – 180°E and 20° – 90°S; for the North Atlantic Oscillation (NAO; Wallace and Gutzler, 1981) and Eastern Atlantic-West Russian pattern (EA-WR; Barnston and Livezey, 1987; Washington et al., 2000), the region over 70°W – 70°E and 20° – 85°N; and for the Pacific Decadal Oscillation (PDO; Trenberth and Hurrell, 1994), the region over 120°E – 75°E and 20° – 70°N. For NAM and SAM, the conventional EOF analysis is used, while for other, the rotated EOF (REOF) is applied. Among the resulting EOF patterns, those patterns whose root-mean-square-errors (RMSE) against the observational/reanalysis patterns are relatively low are chosen.

The RMSE is calculated as:

$$RMSE = \sqrt{\frac{\sum_{1}^{N}(X_i - Y_i)^2}{N}} \tag{1}$$

Where N is the total number of data, X_i is the time series of a variable from the observation, and Y_i is the time series of the same variable from the model simulation.

Unlike other indices, El Niño Southern Oscillation (ENSO) is computed as the mean SST over the Niño3.4 region in 170°W – 120°W and 5°S – 5°N (Trenberth and Stepaniak, 2001).

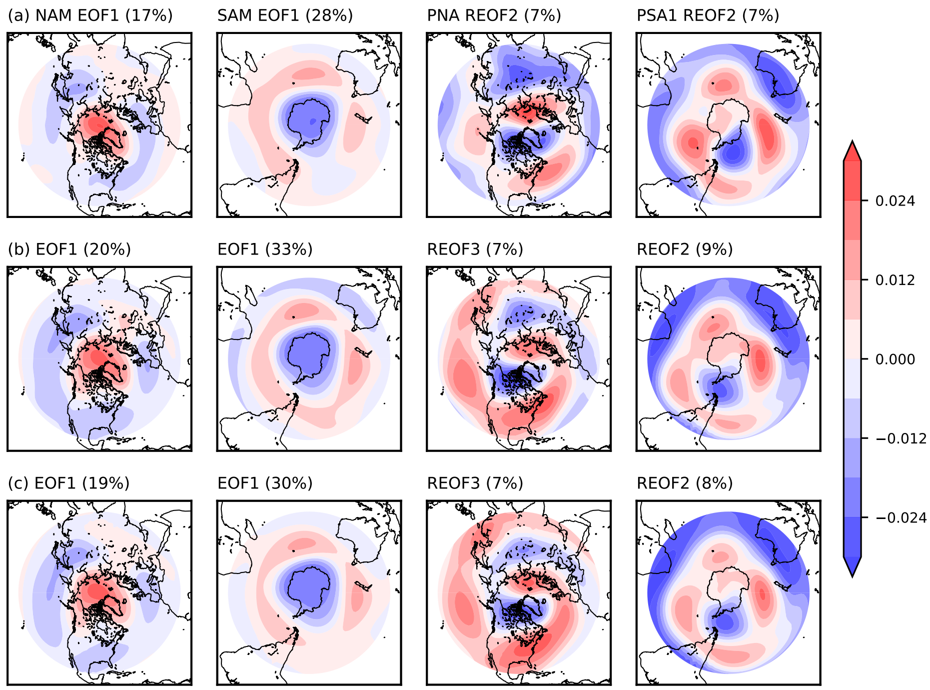

Figure S 1: Modes of internal variability from (a) ERA5, (b) CESM 1979 – 2008 CE, and (c) CESM 1501 BCE – 1849 CE.

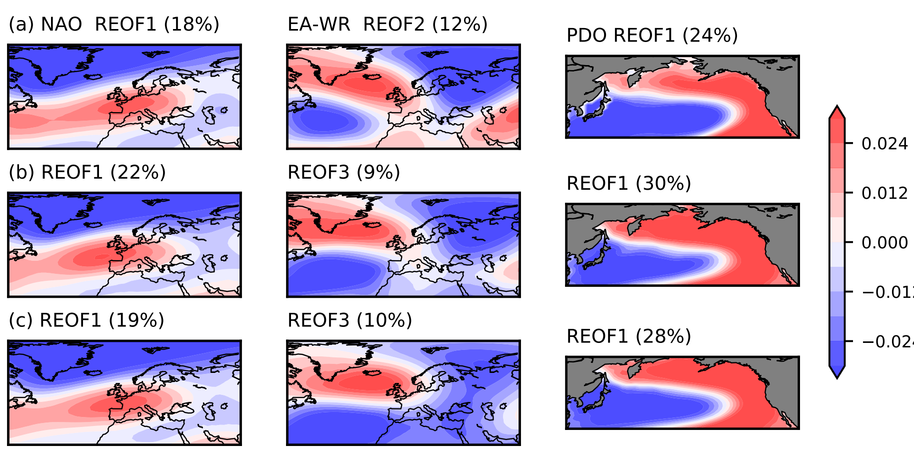

Figure S 2: Continuation of Fig. S 1

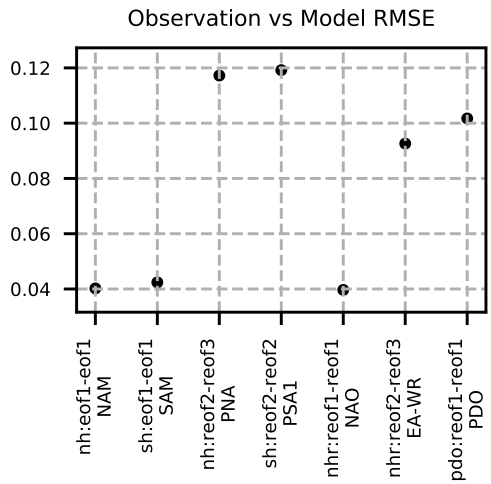

Figure S 3: RMSE between the spatial patterns of the modes of variability of ERA5 and CESM for 1979–2008 CE (Panels a and b in Figs. S 1 and S 2)

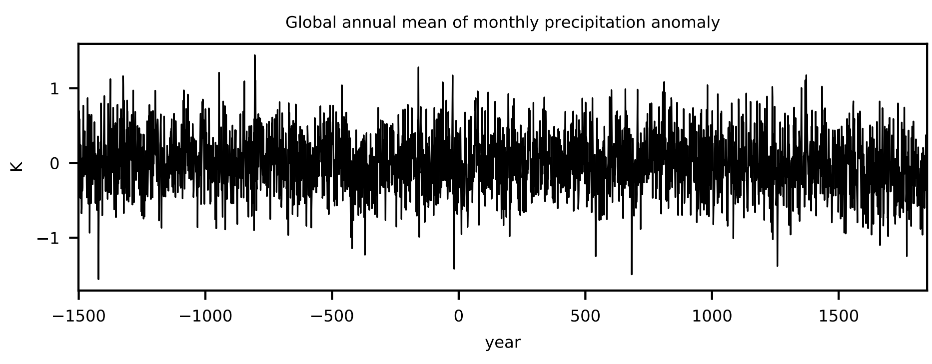

Figure S 4: Globally and annually averaged monthly temperature anomaly from the full-forcing simulation.

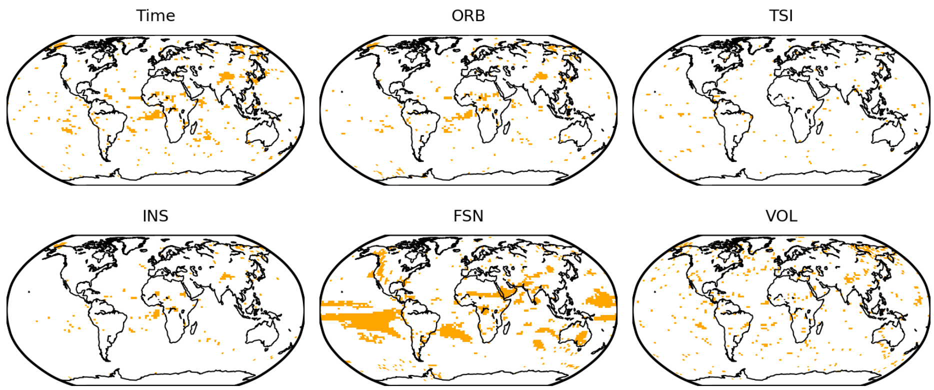

Figure S 5: The external-forcing-GPD models that explains the variability of extreme precipitation better than the stationary GPD model in Fig. 9 at the 99% confidence interval in the full-forcing simulation.

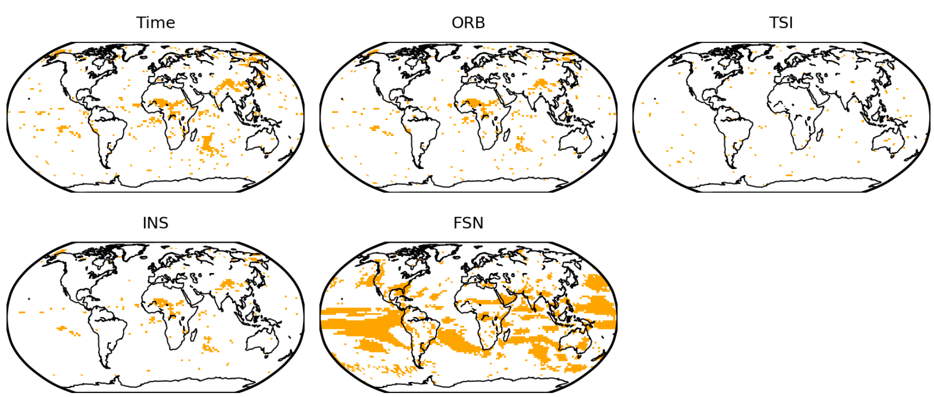

Figure S 6: Same as Fig. S 5 but for the orbital-only simulation.

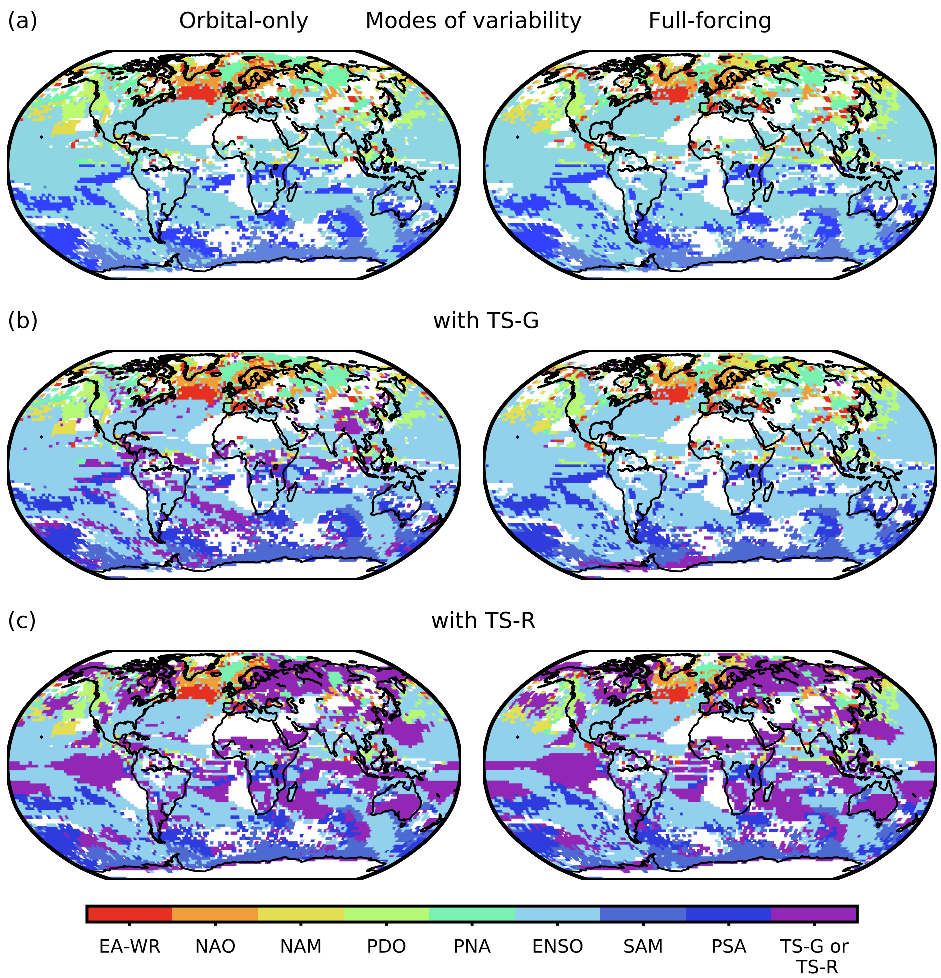

Figure S 7: The non-stationary GPD models with (a) the modes of variability, (b) the modes of variability and TS-G, and (c) the modes of variability and TS-R as covariates, that outperform all other GPD models (the modes-of-variability-covariate, TS-G or TS-R, and stationary models) at 99% confidence interval, hence, explain best the variability of extreme precipitation in orbital-only (right) and full forcing (left) simulations.

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